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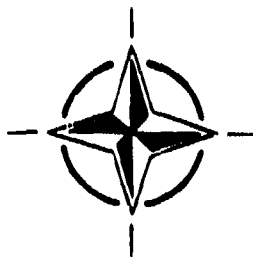
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AGARD REPORT 791

Environmentally Safe and Effective Processes for Paint Removal

(Les Procédés Efficaces et Ecologiques
pour l'Enlèvement des Peintures)

*Papers presented at the 75th Meeting of the AGARD Structures and Materials Panel,
held in Lindau, Germany from 7th-8th October 1992.*



NORTH ATLANTIC TREATY ORGANIZATION

STRATEGIC STATEMENT
Approved for public release
Distribution Unlimited

Published March 1993

Distribution and Availability on Back Cover

REPORT DOCUMENTATION PAGE			
1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-R-791	ISBN 92-835-0705-3	UNCLASSIFIED/ UNLIMITED
5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 Rue Ancelle, 92200 Neuilly sur Seine, France		
6. Title	ENVIRONMENTALLY SAFE AND EFFECTIVE PROCESSES FOR PAINT REMOVAL		
7. Presented at	the 75th Meeting of the AGARD Structures and Materials Panel, held in Lindau, Germany from 7th—8th October 1992.		
8. Author(s)/Editor(s)	Various		9. Date March 1993
10. Author's/Editor's Address	Various		11. Pages 138
12. Distribution Statement	There are no restrictions on the distribution of this document. Information about the availability of this and other AGARD unclassified publications is given on the back cover.		
13. Keywords/Descriptors	<div style="display: flex; justify-content: space-between;"> <div> Paint removers Aircraft Safety </div> <div> Paints Environmental impact </div> </div>		
14. Abstract	<p>Paint stripping and repainting of aircraft surfaces are required periodically during the operating lifetime of an aircraft. Historically, paint removal has been achieved with chemical strippers. These materials often contain toxic components and create hazardous working conditions.</p> <p>It is necessary to ensure that alternate paint removal techniques are available that can be performed in a cost effective, environmentally safe manner without causing damage to aircraft surfaces.</p>		

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Published March 1993

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ISBN 92-835-0705-3



*Printed by Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ*

Preface

Historically, removal of paint from aircraft has been achieved using chemical paint stripping methods. These procedures have utilized toxic components which generate considerable quantities of hazardous waste requiring expensive disposal procedures. Alternate methods for aircraft paint removal are now being investigated within the NATO nations. These processes include:

- Plastic Media Blasting
- Laser Paint Stripping
- Carbon Dioxide Pellet Blasting
- Sodium Bicarbonate Blasting
- Cryogenic Paint Removal.

The SMP held a workshop on Environmentally Safe and Effective Processes for Paint Removal from aircraft. The purpose of the workshop was to review the state-of-the-art of the new technologies for paint removal and their effects on the properties of aircraft structural materials. The practicality of operation, environmental effects, costs and process controls were also discussed in that these factors strongly influence the implementation of alternate paint removal processes.

The workshop format consisted of reviews of alternate paint removal activities in several NATO countries. These were followed by presentations of work on Plastic Media Blasting and other advanced methods of alternate paint removal.

On behalf of the Structures and Materials Panel, I would like to thank the authors whose participation made possible the success of the workshop.

Préface

Dans le passé, la peinture des aéronefs était enlevée au moyen de produits chimiques décapants. Ces méthodes faisaient appel à des ingrédients toxiques qui engendraient des quantités considérables de déchets dangereux, dont l'évacuation s'avérait coûteuse. Des méthodes nouvelles pour l'enlèvement de cette peinture sont actuellement à l'étude au sein des pays de l'OTAN. Ces méthodes comprennent:

- le décapage au jet de matières plastiques
- le décapage au laser
- le décapage par projection de particules de glace carbonique
- le grenailage au bicarbonate de sodium
- le décapage cryogénique.

Le Panel des Structures et Matériaux a organisé un atelier sur les procédés efficaces d'enlèvement de la peinture des aéronefs, sans danger pour l'environnement. L'atelier a eu pour objet de faire le point des nouvelles technologies pour l'enlèvement de la peinture et de leurs effets sur les caractéristiques des matériaux structuraux des aéronefs. Les modalités pratiques de l'application, les effets sur l'environnement, les coûts et les contrôles de processus ont également fait l'objet de discussions, étant donné que ces éléments ont une forte influence sur la mise en oeuvre éventuelle des méthodes nouvelles de décapage.

L'atelier a consisté en une série d'examen sur l'utilisation des procédés nouveaux dans différents pays de l'OTAN, suivie par des présentations sur le décapage au jet de matières plastiques et d'autres méthodes alternatives avancées pour l'enlèvement de la peinture.

Au nom du Panel des Structures et Matériaux, je tiens à remercier les auteurs dont la participation a assuré la réussite de cette manifestation.

Jeffrey Waldman
Chairman, Sub-Committee on
Environmentally Safe and Effective
Processes for Paint Removal

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PAINT REMOVAL ACTIVITIES IN THE U.S. NAVY

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Summary

Use of methylene chloride and phenol based chemical strippers for aircraft paint removal generates large quantities of hazardous waste and creates health and safety problems for operating personnel. This paper presents an overview of the U.S. Navy's activities in the investigation and implementation of alternate paint stripping methods which will minimize or eliminate hazardous waste and provide a safe operating environment. Alternate paint removal methods under investigation by the Navy at the present time include use of non-hazardous chemical paint removers, xenon flashlamp/CO₂ pellets, lasers and plastic media. Plastic media blasting represents a mature technology in current usage for aircraft paint stripping and is being investigated for determination of its effects on Navy composite aircraft configurations.

Introduction

Paint stripping and recoating of the exterior surfaces of Navy aircraft are periodically required during the operating lifetime of the aircraft. Current stripping requirements at the Naval Aviation Depots

(NADEPS) involve in excess of 1000 fixed wing and rotary wing aircraft per year, along with large numbers of components. Toxic and hazardous chemicals such as methylene chloride and phenol have been used historically for paint removal from aircraft and aircraft components. Recently, methylene chloride has been classified as a suspected human carcinogen by the American Conference of Governmental Industrial Hygienists (Ref. 1). It is listed as a toxic organic compound which adds to the total toxic organic (TTO) level in maintenance activity waste streams and the EPA has now classified it a hazardous air pollutant (HAP).

The large quantities of hazardous waste generated by the chemical stripping process require increasingly expensive disposal procedures. Disposal of certain solvents in landfills in the U.S. has been prohibited and incineration of these solvents can cost as much as \$1000 for a 55 gallon drum. Disposal of the contaminated rinse water, sludge and paint residues comprising the hazardous waste generated by paint stripping at the Navy's depots could cost up to a million dollars per year. There are therefore

major environmental and economic benefits to be obtained by the utilization of environmentally safe and effective paint removal methods. In addition to the minimization of hazardous waste, the creation of a safe operating environment offers attendant improvements in employee morale. Reduction in the turnaround time necessary to strip an aircraft provides increased readiness for military aircraft.

Non-Hazardous Chemical Paint Removers

The traditional use of methylene chloride for removal of aircraft epoxy/polyurethane paint systems is attributable to the relatively rapid paint removal rates achievable with this solvent. Several non-chlorinated paint removers have been developed recently which show some potential for chemical paint stripping. A formic acid activated water-based product (Turco 6776) is an effective paint stripper for epoxy/polyurethane paint systems and is currently being used on commercial airliners. However, acid activated paint removers are corrosive to magnesium and are potential sources of hydrogen embrittlement of the high strength steels used as fasteners and in landing gear and arresting hook applications. Two alkaline water-base strippers formulated for the aerospace industry are currently undergoing tests at NAWC, Warminster (Turco 6813 and McGean Rohco 1092). Initial test results indicate much slower strip rates than the

Turco 6776, but also lower corrosivity.

Xenon Flashlamp/Carbon Dioxide Pellet Blasting

In an effort to increase the low paint removal rate associated with CO₂ pellet blasting, Warner Robins Air Logistics Center (WR-ALC) contracted with the McDonnell Douglas Aircraft Company (McAIR), St. Louis, Missouri, for development of a combined xenon arc flashlamp/CO₂ pellet blasting system. By this method, an energized quartz tube filled with xenon gas emits sufficient light energy to ash the paint coating and a high pressure blast of CO₂ removes the residue, leaving a clean and dry surface. McAIR is developing the prototype equipment. A subcontractor, Cold Jet, Inc., Loveland, Ohio, will provide a CO₂ pellet blasting nozzle for attachment to a xenon arc flash lamp. Process optimization and stripping trials were initiated by another subcontractor, Maxwell Laboratories, San Diego, California.

A joint Air Force/ Navy program for evaluation of the effects of this stripping process on materials is underway. The Navy portion of the test program will determine the effects of this stripping method on specific aluminum alloys and graphite epoxy composite substrates. Included in the test plan are fatigue life, crack growth rate and adhesive bond tests of metallic substrates and composite degradation tests of tensile, compressive, interlaminar shear and

flexural strength. Cost benefit analysis, as compared to chemical stripping and plastic media blasting, will also be performed. This will include costs of initial equipment and facilities, maintenance, operation, and cost of removal per square foot of coating for a given coating thickness.

Initial trials have demonstrated feasibility of the system and a paint removal rate for epoxy primer/polyurethane topcoat paint of approximately 1 square foot per minute. The xenon flashlamp/CO₂ system will be demonstrated with robotic controls. The Navy has requested conceptual design review of a non-robotic, air assisted manipulator arm system for fighter sized aircraft. The Air Force test program is underway and the Navy portion of the test program is expected to begin in the Fall of 1992.

Automated Laser Paint Stripping (ALPS)

Under the Navy's ALPS program, International Technical Associates of Santa Clara, California, is developing a robotic aircraft paint stripping system utilizing a pulsed CO₂ laser with a spectral camera system, which will remove coatings selectively, based on the identification of individual surface areas by color. The laser pattern is rastered to minimize heat build-up at the surface. Vadeco International, Inc., Ontario, Canada, will supply robotics, United Technologies Industrial Laser Division (UTIL) will build a 6

kW output power laser system and Grumman Aircraft Systems Division (GASD) will perform an evaluation of the effects of this stripping method on metallic and composite substrate materials. Initial feasibility studies have been conducted and the program has progressed into the design phase. Completed systems are to be installed at both the Norfolk and North Island (San Diego) NADEPS. Details of the ALPS program will be presented at this conference.

Plastic Media Blasting (PMB)

PMB is a production ready process for economical and environmentally advantageous paint removal in place of chemical stripping. It is considerably faster than chemical stripping and reduces operator exposure to health hazards. There is however a potential for damage to sensitive substrate surfaces, so that well trained and skilled operators or robotic controls are required. Hazardous waste, while considerably reduced, is not yet minimized or eliminated.

PMB is currently in use for aircraft paint stripping of metallic surfaces at the NADEPS and is being set up for component stripping at some intermediate levels of maintenance. The Navy has issued a military specification for "Plastic Media, For Removal Of Organic Coatings", MIL-P-85891A. This specification classifies six types of media as follows:

Type I - Polyester
(Thermoset)

Type II - Urea
Formaldehyde (Thermoset)
Type III - Melamine
Formaldehyde (Thermoset)
Type IV - Phenol
Formaldehyde (Thermoset)
Type V - Acrylic
(Thermoplastic)
Type VI - Poly (allyl
diglycol carbonate)
(Thermoset)

PMB on Metallic Surfaces

The Navy has approved PMB of aluminum (and other alloy) airframes and components of 0.016 inches and greater thickness, with a maximum allowable heavy particle media contamination level of 0.02% by weight. A-4 and F-4 aircraft, as well as H-46, H-60, H-53 and H-3 helicopters and numerous components are being stripped at the NADEPS with Type V media.

PMB on Composite Surfaces

The Naval Air Warfare Center, Aircraft Division Warminster (formerly Naval Air Development Center) conducted studies to assess PMB as a paint removal method for AS4/3501-6 and IM6/3501-6 graphite epoxy (Gr/Ep) composite materials. The process variables of media type, media particle size, nozzle pressure, angle of attack and stand-off distance for a fixed nozzle size and media flow rate were investigated. Microstructural examination by optical microscopy and scanning electron microscopy showed that the mechanism of damage was one of surface ablation (Ref. 2). Investigation after 4 repeat paint and blast cycles, by pulse echo

ultrasonic C-scan and by microstructural examination of cross-sections, revealed no evidence of sub-surface damage or delamination.

PMB studies have also been conducted with thin section Gr/Ep composite aircraft structural laminates (Ref. 3). Both Type I and Type II, non-recycled media were used for paint removal at 35 psi nozzle pressure, through a 0.5 inch diameter Venturi nozzle at 700 lb/hr media flow rate. Tension and compression tests were performed in the chordwise laminate configuration to reveal any effects of fiber damage at the surface and four-point flexural tests were performed in both the chordwise and spanwise configurations to reveal any matrix or fiber degradation. No significant losses were observed in mechanical properties.

Type V media has a lower specific gravity (1.20) than Type II media (1.50) and has been found to be less aggressive on composite surfaces, although equivalent paint removal rates of 1-2 sq.ft./min have been obtained. Type V media is in use at the NADEPS and is being used in the Navy's test program of PMB on composite surfaces. For the initial phases of the test program, Gr/Ep panels were laminated with an orientation of (0₂, +/-45, 0, +/-45)s, to provide a flexure sensitive "1st ply failure" configuration. Type V recycled media was used to remove epoxy primer/polyurethane top coat paint under the following conditions:

Media Flow Rate: 500 lb/hr
 Nozzle Diameter: 5/8" ID
 Nozzle Pressure: 30 psi
 Stand-off Distance 6", 12"
 Angle of Attack: 45° and 90°
 U.S. Sieve size: 30-40

Blasting was performed both parallel and perpendicular to the 0 degree surface ply fiber direction. Extended dwell times were multiples (5X, 10X, 15X, 20X and 25X) of the time required to remove the top coat and primer completely from the composite surface. Fiber damage was found to initiate after 10-20 blast cycles, confirming the reduced aggressiveness of the Type V media as compared to Type II (Ref.4). Four-point flexural testing was performed for each of the above blasting parameters for 1, 10, and 20 simulated paint strip cycles. No reduction in strength was observed for any of the blasting parameter combinations at any of the dwell times. Statistically significant increases in flexural strength were found for 75% of the blasted panels. This increase may arise from erosion of the non-structural, resin rich surface, which allows a reduced cross-section to take the same loading as the unblasted control specimen; therefore the load is divided by a smaller cross-section thickness and the measured strength of the blasted specimens is greater.

Conclusions

PMB is a production ready process, well-suited for aircraft and component paint stripping. It does not, however, provide the ideal solution for all coating

removal applications. Increased operating efficiency and additional hazardous waste reduction may be provided by newer technologies.

With the goal of environmental and safety improvements, reduction in operating costs, and improvements in productivity, the Navy will continue to evaluate the benefits and determine the applicability of emerging paint removal technologies to meet Navy needs.

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PAINT REMOVAL ACTIVITIES IN CANADA

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SUMMARY

Paint removal activities currently under way in Canada include: research and development of laser paint stripping;¹ development and commercialization of a new blasting medium based on wheat starch; commercialization of new blasting medium and process using crystalline ice blasting for paint removal and surface cleaning;² and the development of automated and robotic systems for paint stripping applications.

A specification for plastic media blasting (PMB) of aircraft and aircraft components is currently being drafted by NDHQ for use by the Canadian Armed Forces (CAF) and contractors involved in coating removal for the CAF. Defence Research Establishment Pacific (DREP) is studying the effects of various blast media on coating removal rates, and minimizing the possibility of damage to substrates other than aluminum such as graphite epoxy composite and Kevlar. The effects of plastic media blasting on liquid penetrant detection of fatigue cracks is also under investigation.

1. DEVELOPMENT OF A MILITARY STANDARD

The Canadian Armed Forces (CAF) is preparing a specification for paint removal from aircraft and aircraft components using plastic media blasting (PMB). This specification will include parameters to control media flow rates, standoff distance, blast angle and media type for a variety of substrates including forged, anodized and clad aluminum, graphite epoxy composites, and magnesium alloys.

The CAF is preparing to remove the coatings from CF-18 aircraft during complete overhaul. This will be the first time the coatings on these aircraft have been completely removed. The plan is to use Type V (acrylic) plastic media starting in 1993. A dedicated PMB facility is under construction by a contractor, Canadair, and all CF-18 aircraft will be stripped at this facility. Other aircraft types will be stripped by other contractors and the facilities will vary with the contractor.

Type V plastic media will also be adopted this year as the medium for use in the PMB booths for depot level maintenance of components. Aluminum, clad and bare, graphite epoxy composite and other metal components will be stripped in PMB booths.

Other blasting media are also under consideration for use by

the CAF. DREP is investigating the possible use of TYPE VI (allyl diglycol carbonate) and wheat starch to replace the Type V plastic media. Before any new media are accepted for use by the CAF, research into the stripping rate, blasting parameters, possibility of substrate damage, and residual stress measurements using the almen arc procedure will be carried out.

The effects of different blasting media and the choice of blasting parameters on the detection of surface and fatigue cracks using the fluorescent penetrant (LPI) detection method have been investigated. Research has shown that the Type V plastic media can be used successfully on forged aluminum components as long as the flow rate of the media is controlled to reduce the surface residual stress produced from media blasting. Crack smearing is not a problem on bare 7075-T6 plate using either Type II or Type V plastic media. On clad 7075-T6 plate crack detection is difficult after one or two blast cycles due to smearing of the cladding which prevents detection of cracks by the LPI method.³

2. LASER PAINT STRIPPING

In Canada, the use of continuous wave (CW) and pulsed CO₂ laser for de-painting has been investigated by Merchant and Bonkowski at The Laser Institute.⁴ They found that paint removal using laser radiation is dependant on both the power per unit area (intensity (kW/cm²)) and energy per unit area (fluence (J/cm²)) of the laser beam and the type of substrate to which the paint has been applied. The authors concluded that there are effective parameters for each substrate including laser power and energy, focal distance, and laser mode, that leads to effective laser stripping of coatings.

Paint removal by laser radiation is by one or both of two mechanisms, vaporization and combustion. For example, if a stream of air is directed at the painted surface during laser stripping the paint removal is more efficient than if a stream of inert gas, which prevents combustion, is directed at the paint surface. The stream of air allows the paint to combust as well as vaporize whereas the stream of inert gas only allows the paint to vaporize.

Care must be taken when using laser stripping because the substrate surface can reflect or absorb the laser radiation, and the nature of the surface also affects the rate of paint removal. On an anodized aluminum surface the laser radiation from a

CO₂ laser is absorbed by the oxide layer and the parameters required to strip paint must be more closely controlled than on a reflective surface such as aluminum metal. After laser paint removal there is no residual paint film left on the anodized surface whereas there is always a residual paint film left on the aluminum surface. On a reflecting surface, as the paint film is reduced in thickness during laser stripping, the amount of laser energy absorbed by the thin paint film is reduced as more of the radiation is reflected from the substrate surface. At some point vaporization of the thin paint film no longer occurs.

Laser stripping of a coated carbon steel, which also is a reflecting surface for CO₂ laser radiation, resulted in visual damage to the steel surface. Microscopic examination of the steel surface revealed a change in microstructure to a depth of 150 μm at 800 J/cm² and 100 kW/cm² of laser energy and power. At lower energy and power, 40 J/cm² and 60 kW/cm² respectively, no damage was observed but, as with the reflective aluminum, a thin layer of paint remained on the surface.

In practice laser stripping would require a robotic system to ensure the partially de-focused laser beam was moved across the surface in a controlled manner to prevent surface damage and to maintain paint removal efficiency. Laser stripping is less costly than chemical stripping.

3. ICE BLASTING

Ice blasting will be discussed in more detail in a subsequent paper.² Ice blasting was developed by RETECH³, under contract to DREP, as a dust free blasting technique for confined spaces such as ship bilges and machinery spaces. More recently it has been shown to have further application in paint removal from delicate substrates that can be damaged by conventional blasting techniques and as a cleaning technique for soiled or contaminated surfaces.

Ice particles offer several advantages as a blasting medium. Ice particles are not abrasive and fracture under a high load such as impact with a substrate, limiting the impact force and thereby preventing damage to delicate substrates. Ice is also a dust free media that melts to water. The spent medium, water, can be easily removed from the coating debris and can be disposed of leaving the coating debris to be handled as a known hazardous waste disposal problem.

The use of ice blasting is also being considered by the CAF as a method for cleaning soiled aircraft coatings, removing decals from aircraft, removing paint from delicate surfaces such as Kevlar and graphite epoxy composites, and as a possible method to clean aircraft components such as gas turbine blades.

Concerns about the environmental aspects of the disposal of

the spent media from plastic media blasting or traditional grit blasting could lead to more serious consideration of ice blasting for the stripping and cleaning of entire aircraft or other equipment.

4. WHEAT STARCH BLASTING MEDIA

Wheat starch blasting media will also be discussed in more detail in a subsequent paper⁴ and only a brief summary will be included here. Wheat starch was developed by Ogilvie Mills Ltd⁵, Montreal Canada as a biodegradable, non-toxic, non-petroleum, natural polymer abrasive grit for paint removal.

Wheat starch has several advantages over conventional plastic media. This medium is softer than Type II or Type V media and thus the possibility of damage to delicate substrates is reduced. It is much easier to remove one coating layer at a time with wheat starch than with other plastic media. Wheat starch is a natural material and there are minimal disposal problems.

Wheat starch is under consideration by the CAF as a possible blasting media. Research is currently under way to investigate the parameters necessary for efficient paint removal and to determine the benefits of wheat starch over Types V and VI plastic media. Wheat starch is also under consideration for special applications such as stripping decals and removing paint from sensitive substrates, such as Kevlar.

Economic and environmental concerns about the disposal of used media could also bring wheat starch into more serious consideration in the future.

5. ROBOTIC PAINT STRIPPING

A robotic paint stripping system has been developed by Computrip Systems.⁶ This system has been demonstrated successfully on large transport and passenger type aircraft.

The robotic system has sensors to prevent damage to the aircraft from movement of the robotic arm and blast head. The blasting parameters such as media flow rate and blast pressure and the movement of the blast head are controlled from one main control centre. The Computrip robotic system uses a vacuum recovery system around the blast head, which incorporates two blast nozzles, to capture and recycle the used blast media. The air cleaning, media recycling and high pressure systems are identical to those found with the normal, commercially available plastic media blasting equipment.

The size of the blast head makes it difficult to envision its use on small fighter aircraft. This type of blast and recovery system is much more efficient if the blast head can travel over long, straight distances. The blast system can use any of the

plastic media and is currently operating with Type V blasting media.

The Compustrip system does not require an area dedicated to paint stripping. This is because all of the spent blast media is recovered at the blast head and recycled in the recovery system, leaving the area where the aircraft is being stripped free of contamination from dust and blast media. The advantage of this system is that it can be used in areas not traditionally used for paint stripping.

Vadeko International Inc.⁹ initially developed robotic paint application systems for the aerospace and transportation industries. The development of automated paint removal systems was a natural next step. The automation of the following paint removal techniques has been investigated:

- 1) plastic media blasting for space flight hardware,
- 2) laser paint stripping for aircraft skins, AND
- 3) dry ice blasting for transit cars and aircraft skins.

The automation of paint removal techniques has several advantages over manual removal techniques. The automated process is repeatable and controllable, especially for laser paint stripping where dwell time and standoff distance can be readily controlled to prevent damage to the substrate.

For durable surfaces such as steel, automation offers high quality process control. For example, on the re-usable space rocket booster, automation combines a high degree of process control, standoff distance and media flow, with the ability to record process parameters to establish a performance log.

Environmental concerns are an impetus for the automation of aggressive media blasting (eg. sand, grit, and alundum). Closed circuit blasting tools that include a blast nozzle and vacuum and media return lines and require that close attention be paid to standoff distance to effectively contain the blast spray are more reliable if operated by automatic means.

6. CONCLUSIONS

The CAF is developing a specification for the introduction of plastic media blasting as the approved method of paint removal on aircraft to replace the current chemical stripping methods.

Two new blasting materials and processes, ice particles and wheat starch, have been developed in Canada over the last few years and are being considered for use by the CAF. Ice

blasting has the advantages of being non-abrasive, dust free and the spent media and coating debris can be easily separated for disposal. The advantage of wheat starch is that it is biodegradable and not as aggressive as plastic media.

Over the next few years automated methods of paint removal will have to be considered especially for laser stripping technology. Automation provides the advantage of giving some assurance of meeting environmental protection regulations when removing coatings.

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**PROCEDES SANS DANGER POUR L'ENVIRONNEMENT ET EFFICACES (PSDEE)
POUR L'ENLEVEMENT DES PEINTURES**

POINT SUR LES ACTIVITES FRANCAISES CONCERNANT L'ENLEVEMENT DES PEINTURES

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Résumé : Le texte suivant présente de manière synthétique les activités et les sujets d'intérêts français pour les nouvelles techniques d'enlèvement des peintures dans le secteur aéronautique civil et militaire.

1 - OBJECTIFS

Mise au point et mise en oeuvre de solutions non toxiques pour le décapage des peintures, en remplacement du décapage chimique.

Principaux inconvénients présentés par le décapage chimique :

- non sélectivité dans le décapage des différentes couches, constitutives des gammes,
- non compatibilité avec les éléments en Composites,
- non respect des règles d'hygiène et sécurité,
- non respect de l'environnement.

Objectifs recherchés avec les nouvelles techniques de décapage :

- décapage sélectif des différentes couches de peintures,
- utilisation possible à la fois sur surfaces métalliques et sur composites,
- aucun endommagement des structures, ni des traitements de surfaces,
- possibilité de remise directe en peinture,
- non toxicité, de façon à satisfaire aux exigences concernant la santé, la sécurité et l'environnement,
- mise en oeuvre simple et économique.

2 - POINT SUR LES "PSDEE" POUR L'ENLEVEMENT DES PEINTURES

2.1 - Projection de Média-Plastiques (P.M.P)

2.1.1 - Généralités :

Définition du procédé : enlèvement mécanique des peintures par projection sous faible pression de particules abrasives (famille des thermodurcissables) classées en différentes catégories :

- type 1 : Polyester,
- type 2 : Urée Formaldéhyde,
- type 3 : Mélamine Formaldéhyde,
- type 4 : Phénol Formaldéhyde,
- type 5 : Acrylique.

Ces média-plastiques, qui se présentent sous forme de fins granulés, sont disponibles avec des granulométries, des masses et des duretés différentes.

Mise en oeuvre du procédé :

- soit par projection en jet libre, en cabine ou en salle spécifique,
- soit en circuit fermé, avec pistolet ou turbine de projection, système de récupération, et dispositif évitant les projections extérieures.

2.1.2 - Les P.M.P dans les APPLICATIONS AVIONS (AEROSPATIALE)

1987/89 :

- Essais de faisabilité, en cabine de projection, sur tous les supports (cf. planche AS n°1),
- essais de caractérisation mécanique des supports après décapage,
- optimisation des paramètres de décapage : type de média, type et diamètre de buse, angle de projection, distance, pression, débit, durée (cf. planche AS n°2),
- étude d'un système de vision pour le contrôle de l'enlèvement de la peinture (caméra CCD couleur + traitement d'images - cf. planche AS n°3).

1989/90 :

- Etude de l'influence de décapages successifs sur les substrats,
- caractérisation et qualification des Média-Plastiques (cf. planches AS n°4 et n°5),
- mise au point des gammes de préparation de surface pour les parties métalliques et composites.

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**CTMS : Centre Technique des Matériaux et Structures

1991/92 :

- Contribution au développement de 2 systèmes de décapage P.M.P robotisés (COMPUSTRIP et SCHLICK) en vue d'essais comparatifs à réaliser courant 1992 sur une cellule d'avion TRANSALL peinte avec la gamme Airbus.

2.1.3 - Les P.M.P. dans les APPLICATIONS HELICOPTERES (EUROCOPTER)1986 :

- Mise en oeuvre d'un système automatisé de décapage P.M.P (SCHLICK) pour les pales d'hélicoptères en matériaux composites (site de LA COUR-NEUVE) ⇒ gain de temps de 70% pour une pale type PUMA.

1987/89 :

- Mise en oeuvre de deux installations de décapage P.M.P. en cabine (MATRASUR et SCHLICK) pour l'enlèvement des peintures sur les éléments mécaniques (site de MARIGNANE) ⇒ capacité de traitement : 1500 kg de pièces par jour.

1992 (en projet) :

- Salle de décapage P.M.P. pour l'enlèvement des peintures sur les cellules d'hélicoptères (site de MARIGNANE)

2.1.4 - Les P.M.P. dans les COMPAGNIES FRANCAISESAIR FRANCE :

- Essais de décapage P.M.P. robotisé (en laboratoire) sur des parties démontables (non structurales) métalliques et composites.

- Participation à la mise au point d'une installation de décapage P.M.P. robotisée assistée par un système de vision basé sur l'analyse d'images (en coopération avec l'AEROSPATIALE et d'autres).

- Participation à un programme d'essais concernant l'influence d'opérations successives de décapage P.M.P. (en coopération avec BOEING et d'autres).

- Participation au groupe de travail IATA "Décapage des peintures", créé en 1990 et ayant pour objectifs :

- l'identification des solutions de remplacement les plus prometteuses,
- la préparation d'un document devant contenir les exigences techniques pour la qualification des procédés de remplacement,
- le développement d'échanges entre chercheurs, constructeurs d'avions, compagnies aériennes, fournisseurs de peintures et de produits de décapage.

- Etude de faisabilité et d'approche du système de décapage robotisé COMPUSTRIP réalisée en juillet 92 sur un BOEING 727.

UTA :

- Mise en service, en 1987, d'une salle de décapage (dim. 6 x 4 x 3 m) pour le traitement des pièces de grandes dimensions métalliques et non métalliques, à l'exception des composites verre / époxy (installation non robotisée, 2 buses de projection, média type 2).

- Participation au groupe de travail IATA "Décapage des peintures".

IAT :

- Equipement de décapage P.M.P. (5 canons, non robotisé, capable de traiter un Boeing 737) en service depuis mai 1991 à l'aéroport de RODEZ-MARCILLAC (Installation PAULI & GRIFFIN).

2.1.5 - Les P.M.P. à AIRBUS INDUSTRIE

Faisant suite à une étude sur les P.M.P. lancée fin 1987, une spécification de procédure Airbus Industrie (AIPS 02-100) relative au décapage P.M.P. des peintures est disponible depuis le début 1990.

Cette AIPS, applicable aux avions A300, A300-600, A310 et A320, définit les conditions de travail et les recommandations qui doivent être rigoureusement respectées, afin d'éviter un endommagement important de la protection par anodisation ou placage sur les parties métalliques, ou des couches de fibres sur les parties en composites.

2.1.6 - Les P.M.P. dans l'ARMEE de l'AIR FRANCAISE

Décapage P.M.P. en cabines (MATRASUR, INTER-BLAST, SCHLICK) sur les parties démontables, métalliques (blocs de freinage, roues...) ou composites (éléments non structuraux).

En projet : installation de décapage P.M.P., en cabine, pour l'enlèvement des peintures sur radômes suite aux conclusions d'essais réalisés dans le cadre d'un groupe de travail créé pour l'évaluation technique et économique du procédé (site de CUERS-PIERREFEU).

Essai de décapage P.M.P. sur cellule MYSTERE 20 (Installation INTERBLAST non robotisée).

En projet : installation de décapage P.M.P. robotisée pour l'enlèvement sélectif ou total des peintures sur avions militaires (site de CLERMONT FERRAND).

2.1.7 - Les P.M.P. et la NORMALISATION

Un groupe de travail (GT 10/2) du BNAé (Bureau de Normalisation de l'Aéronautique et de l'Espace) est actuellement en train d'établir les spécifications à l'attention des fournisseurs de Média-Plastiques, de façon à satisfaire aux exigences des constructeurs (cf. projet de norme Pr.L06 - 850 intitulé "Produits de projetage - Particules plastiques - Spécifications techniques").

Parallèlement l'AEROSPATIALE - Direction Générale de la Qualité - a édité une Instruction Générale de Contrôle intitulée "Produits de projetage - Particules plastiques" référencée IGC 04-71-125.

2.1.8 - LIMITATIONS D'EMPLOI des P.M.P.

L'utilisation du procédé P.M.P. est déconseillée dans les cas suivants :

- sur les tôles de faible épaisseur \Rightarrow risque de déformation lorsque l'épaisseur est inférieure à 1,2 mm,
- sur les pièces devant faire l'objet d'une recherche de fissures :

\Rightarrow risque de colmatage par les débris

\Rightarrow risque de repoussage mécanique des lèvres des fissures (sur pièces en alliages de magnésium et, dans une moindre mesure, en alliages d'aluminium).

- sur les matériaux contenant des silicones \Rightarrow risque de contamination des média-plastiques.

2.2 - Les nouvelles Techniques

2.2.1 - L'AQUASTRIpping

Participation de la Compagnie AIR FRANCE au programme LUFTHANSA d'essais de décapage à l'eau sous haute pression (procédé duplex utilisant un produit chimique "léger" pour ramollir la peinture avant l'opération de décapage par projection d'eau sous pression (300/500 bars).

2.2.2 - Le procédé CRYOCLIN

Ce procédé, décapage par projection de particules de glace après ramollissement préalable de la peinture, est actuellement étudié sur éprouvettes d'essais à AIR FRANCE et UTA.

Des essais positifs ont également été réalisés sur aubes de turbines, jantes de roues et pièces de trains d'atterrissage.

2.2.3 - Le procédé COLDIET

Ce procédé, décapage par projection de particules de glace carbonique après ramollissement préalable de la peinture, a fait l'objet d'essais sur éprouvettes ainsi que sur pièces. Il paraît, à l'heure actuelle, plus intéressant pour le nettoyage que pour le décapage.

2.2.4 - Le procédé LASER

Ce procédé (décapage de la peinture par technique Laser CO2 ou Excimere), mis au point pour l'industrie nucléaire et caractérisé par une très faible productivité, est l'objet d'une veille technologique.

Quelques essais sur éprouvettes ont été réalisés à ce jour, en particulier par AIRFRANCE et UTA.

2.2.5 - Le procédé DUPLEX

Ce procédé, décapage de la peinture par alternance d'une irradiation à haute température par une lampe Xénon de chauffage et d'une projection de CO2, est l'objet d'une veille technologique.

2.2.6 - Les autres Techniques et la Normalisation

Aucune activité de normalisation, à l'heure actuelle, dans ce secteur.

3 - TENDANCES ACTUELLES

L'AEROSPATIALE et AIR FRANCE, les 2 chefs de file français dans le domaine de l'enlèvement des peintures, de même que DASSAULT AVIATION et les Centres de Révision des avions militaires, pensent que l'avenir proche réside dans les couches intermédiaires (couches "barrière" ou d'avertissement"), de manière à améliorer la productivité du décapage par P.M.P. (cf AEROSPATIALE), ou celle des autres techniques (cf AIR FRANCE).

Il est à noter qu'AIRBUS INDUSTRIE a très récemment (mai 1992) donné son agrément pour une gamme de peinture à couche intermédiaire (gamme MAP).

process feasibility

Representative specimens

metallic specimens

2024 PL T3
CAA (conversion coating)
primer PAC33
top coat PU66
ageing 750 h/98% Hr/50 °C

composite specimens

carbon/epoxy
primer PU5425
top coat PU66
ageing 750 h/98% Hr/50 °C

Requirements

stopping criteria

selective stripping = until the primer coat appears

total stripping (metallic specimens) = until the CAA appears

no damage on substrate

repeatability / homogeneity on stripped surfaces

Media

type II : urea formaldehyde Grade B size 30/40

Tests

optimisation of the process parameters

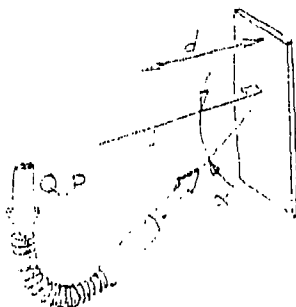
influence on the substrate after one stripping

influence on the substrate after repetitive strippings

Planche AS No. 1

process characterization results

Optimisation of the process parameters



metallic specimens

$3 \text{ m}^2/\text{h}$
 $Ra = 6,5 \text{ } \mu\text{m}$

composite specimens

$9 \text{ m}^2/\text{h}$
 $Ra = 6,5 \text{ } \mu\text{m}$

$\alpha = 30^\circ$
 $d = 250 \text{ mm}$
 $p = 2 \text{ bar} = 0,2 \text{ MPa}$
 $q = 2,3 \text{ Kg/min}$

Damage on substrates : metallic and composite specimens

after one stripping \rightarrow no damage

after 3 (stripping + repainting) \Rightarrow first approach = damage

Planche AS No. 2

process control by vision system

why to control ?

thickness of paint layers (+/- 25 μm)

weathering of paints

not foreseeable

how to control ?

- * infrared sensors and signal processing
- * color CCD camera and image processing

Aerospatiale Joint Research Center activities

feasibility demonstration with a CCD color camera

- * recognition of the paints on representative specimens
- * measurements and localization of the unstripped surfaces
- * time for image processing compatible with a real time control

Planche AS No. 3

media characterization

Specification

definition of requirements : in relation with a repetitive and not damaging process

definition of quality criteria

definition of associated test methods

definition of data sheets for each media

Standardization

with agreement of suppliers / purchasers

Aerospatiale standardization = IGC

french standardization = BNAE/AFNOR NF

european or worldwide standardization = AECMA prEN /ISO standard?

Planche AS No. 4

Example of data sheet

Désignation : UF <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> (voir § 3)			
Matériau : UREE FORMALDEHYDE		Famille : thermodurcissable	
N°	CONTROLE		EXIGENCE
			Grade A Grade B
1	Aspect		Formes et dimensions régulières, absence de corps étranger et d'humidité.
2	Odeur		Absence d'odeur inhabituelle et persistante
3	Matériau		Voir annexe 7 (suite)
4	Granulométrie		Conforme à la granulométrie exigée à la commande.
6	pH		$4 \leq \text{pH} \leq 8$
5	Dureté Barcol		$54 \leq \text{Barcol} \leq 62$
7	Masse volumique	g/cm ³	$1.47 \leq \rho \leq 1.52$
8	Absorption d'eau	% en masse	≤ 10
9	Teneur en composés organo-solubles	% en masse	≤ 0.5
10	Teneur en particules lourdes	% en masse	≤ 0.01

Planche AS No. 5

Paint Removal Activities in Germany

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1. SUMMARY

To replace paint removing chemicals containing chlorinated hydrocarbons several alternative paint stripping methods have been developed or are under study in Germany:

- high pressure water stripping
- plastic media blasting
- use of alkaline and acid activated softeners
- CO₂ pellet blasting
- laser application.

2. INTRODUCTION

Paint removal activities in Germany are forced by laws which will forbid in near future chemicals containing chlorinated hydrocarbons because of their environmental pollution and toxicity in near future.

It is clear that conventional chemicals are very effective and with more and more resistant paint systems paint removal will become more difficult. Therefore in Germany various attempts have been made in developing alternative paint removal methods.

Table 1 gives an overview on these methods indicating also their state and applicability. Paint removal by high pressure water and plastic media blasting will be reviewed only very short because on these items special papers are presented (Ref 1, Ref 2).

3. AQUA JET STRIPPING

High pressure cold and warm water is used world wide for cleaning. At Lufthansa (Ref 1, Ref 3) this technique has been adapted for paint stripping. For this purpose a special nozzle has been developed spraying 38 l/min of water on the surface under a certain angle. The pressure of the water goes up to 500 bars. By the recoil of the water jet the nozzle is turning with frequencies between 150 and 200 Hz. Due to this pressure variation paints are removed from the surface in a combination of cracking and peeling off.

The effectivity of aqua jetting is highly depending on the condition of the paints p.e. thickness and ageing conditions. To guarantee a high effectivity surfaces are pretreated with alcohol based softening agents reacting 2 - 4 h with the paints before the water jet is applied.

To date a semi robotic system is installed with one manipulator containing 6 nozzles. Fully equipped the aqua jet stripping system will work with 4 of these manipulators allowing to remove the paint from a Boeing 747 in only one 8 h shift. About 200 m³ of water will be used and recycled by 97 %. 2.5 t of formerly used chemicals containing chlorinated hydrocarbons will be replaced by 2 t of biodegradable softening agents.

Table 1: Overview on alternative paint stripping methods

methode	additionally supported by	state	applied on	developed at
Aqua Jet	softeners	large scale	civil aircrafts	Lufthansa
Plastic media	-	large scale	military aircrafts	BWB, MBG
non acid and acid softeners	heat	large scale medium scale experimental	civil/military	Lufthansa DA, Dornier
CO ₂ pellets	softeners	experimental	civil/military	DA, Dornier
CO ₂ pellets	flashlamp	experimental	civil/military	DA, Dornier
Laser		experimental		Dornier, BRITE

4. PLASTIC MEDIA BLASTING

Plastic media blasting is up to now used for military aircrafts only. The "DRY STRIPPING" process (Ref 4) (controlled plastic media blasting) was developed by the DASA engineering maintenance group as an adaption to the general properties of military a/c metal and fiber composite structures. After running a voluminous testing program which covered all influences of the blasting process to substrates a new DRY STRIPPING facility has been built in 1991 at Manching military maintenance plant. Environmental problems caused by chromate containing dusts were solved by the use of local evacuation systems with a following filter battery. The process has been approved by the GA. Up to now 75 a/c have been stripped successfully.

To date german MoD is experiencing plastic media blasting at "Wehrwissenschaftliches Institut für Materialuntersuchungen" (WIM) at Erding (Ref 2). After promising results obtained on aircraft components it is planned to install a large facility at Jever airbase.

5. SOFTENERS

To avoid chlorinated hydrocarbons in the last years alternative paint removing chemicals - so called softeners - have been developed. In several cases they are based on alcohols. Softeners are assumed to be less polluting and they are biodegradable. They are already applied p.e. at Lufthansa as a treatment prior to aqua jet stripping.

Softeners are available as alcale or acid activated pastes or liquids. Generally acid activated softeners are assumed to be more effective.

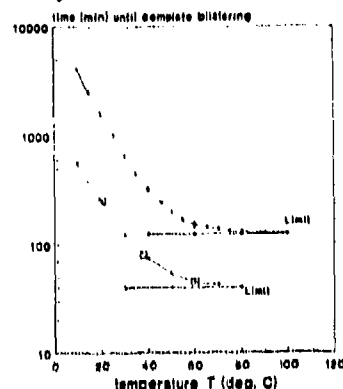
At Dornier several studies have been performed concerning the effectivity and the influence to the base materials of these chemicals.

5.1 Effectivity

Because of their different additives and cross linkages paints of a certain group - polyurethans p.e. - react very different with softeners. While a product A shows blistering over the whole surface already after 30 min, a product B reaches the same surface state after 10 h at 40 °C, and a product C is blistering only partially after 24 h at 40 °C.

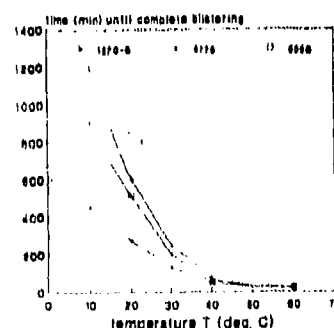
The easiest way to remove paints is by wiping. This is possible only after complete blistering. Blistering is due to sufficient diffusion of agents into the paint and reacting at interfaces or special points (intermediate coatings). The diffusion is of course time dependent, but diffusion also depends on temperature (Boltzmann's law). From this, with increasing temperatures diffusion velocities increase and reaction times decrease. Fig. 1 shows this for the reaction of a non acid softener with two paint systems.

Fig. 1: Reaction time until blistering as a function of temperature for 1270/5 (Ref 5) with two paint systems



At room temperature the acid activated softeners react faster with paints than the alcalic one. But with increasing temperatures differences in reaction times become smaller (Fig. 2).

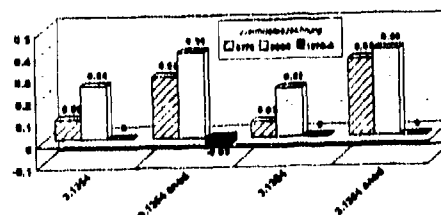
Fig. 2: Reaction time as a function of temperature for acid and non acid softeners (Ref 5)



5.2 Reactions with aluminium

From safety reasons paint stripping agents are not allowed to attack base materials. Bare and chromic acid anodized 3.1354 and 3.1364 have been treated with softeners at 40 °C for 8 h to study the influence. In the case of acid activated softeners a loss of weight was observed (Fig. 3).

Fig. 3: Loss of weight due to softener application



By scanning electron and optical microscopy the removal of the oxide layers and beginning corrosion was detected. In contrary to this no changes of the surfaces have been seen after the 1270/5 treatment. Within measurement errors no reduction of fatigue behaviour (Fig. 4) or strength (Fig. 5) was found after the 8 h 40 °C softener treatment in both cases.

Fig. 4: Fatigue measurements of 3.1354 before and after softener treatment

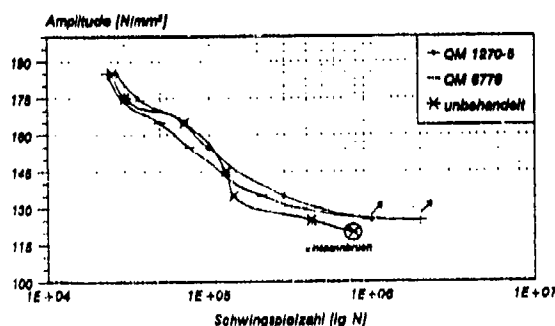
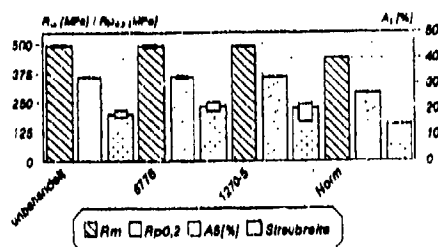


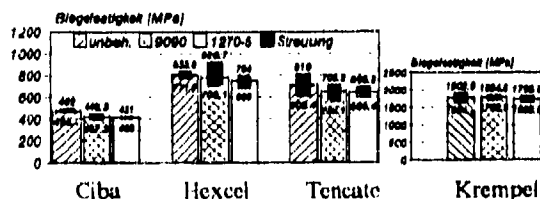
Fig. 5: Strength of 3.1354 before and after softener treatment



5.3 Reaction with composite materials

Applied on fiber composite materials flexural strengths of 3 duroplasts and one thermoplast are not or tolerable effected by an 8 h treatment at 40 °C either with non acid activated nor with acid activated softener (Fig.6). But in the case of the thermoplast the interlaminar shear strength is markedly reduced by all softeners - even after a recovery phase of about 10 days.

Fig. 6: Flexural strength of composites before and after softener treatment



To avoid electrical charging, copper meshes are often laminated into the surface of composite materials. For example 70 % of the surface of the European Fighter Aircraft consist of such material. Using the non acid softener no influences neither on the copper nor on the surrounding material are to be seen. Using acid activated softeners, we find a strong attack on the copper, as well on filaments at the surface as on filaments covered by resin material with accumulation of decomposition products in small cavities and ruptures of these cavities to the surface.

5.4 Conclusion

To conclude, on aluminium acid containing softeners may lead to surface damage and corrosion, while non acid containing do not. No reduction of mechanical strength was observed for both kinds of products. On composite materials, both kinds of softeners are applicable to duroplasts: no important reduction of flexural strength and interlaminar shear strength have been observed. In the case of thermoplasts: all benzylalcohol based paint softeners reduced the interlaminar shear strength to an intolerable level. The use of acid containing softeners is forbidden on composite materials with laminated copper meshes because of copper corrosion.

6. PAINT STRIPPING METHODS UNDER STUDY

As alternatives to conventional chemicals and alternative methods described above following paint stripping methods are in an experimental state in Germany:

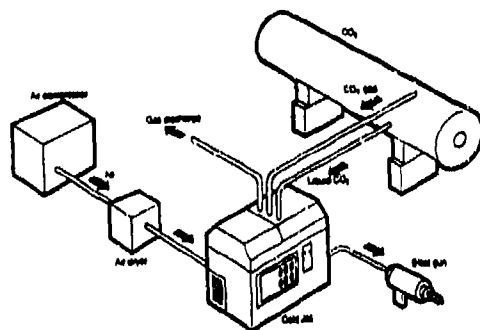
- CO₂ - pellet blasting
- laser application.

The common aim of both methods is to leave no debris other than paint residues.

6.1 CO₂-pellet blasting

Application of CO₂ pellets has the advantage, compared to other blasting media, that no blasting substances are remaining because of the CO₂ evaporation. CO₂ is a - not welcomed - byproduct of chemical processes or may even be gained from environment. CO₂ blasting facilities are available and a series of experimental work was performed in a cooperation of Deutsche Airbus, Dornier, and Messer Griesheim Company providing the CO₂ blasting facility. The scheme of the facility is shown in Fig.7.

Fig. 7: Scheme of CO₂ pellet blasting facility
(from Ref 6)



6.1.1 Paint removing

From our experiments on more than ten paint systems we learnt that effective paint removal is only possible after a proper pretreatment of the paints with chemicals. For example: a PUR-paint system with an intermediate layer showed after a softener treatment of 17 h at room temperature only partial blistering. Moving the CO₂ beam of 5 cm width with a velocity of 24 m/h over the sample - this would be a maximum stripping rate of 1,2 m²/h - only the blistered parts were removed properly. With typical machine parameters of 20 bars pressure and a feeder rate of 30 % - i.e. a CO₂ consumption of 600 kg/h - we typically reached following removal rates: less than 1 m²/h for untreated paints and more than 15 m²/h for well prepared paint systems. Of course times for proper reaction were depending strongly on paint systems used.

6.1.2 Mechanical and thermal load

To study mechanical load and vibrations sensors were fixed on the backside of samples. With a low speed corresponding to a stripping efficiency of 1 m²/h the mechanical load was 6.5 MPa. Stress reversals of 10⁴ for this low efficiency are orders of magnitude lower than allowed.

With a CO₂ particle temperature of -70°C it is important to know temperatures reached on samples. To measure this a thermocouple was fixed on the back side of a 1.2 mm thick aluminium sheet (size: 30 cm x 24 cm). In the static case with spraying the particle beam for 50 s on the back side a lowest temperature of -20°C was measured. Moving the beam with a low velocity of 17 m/h ($F_{max} = 0.85$ m² maximum stripping rate) above, across, and below the measuring point, lowest temperatures of about -15°C were found.

Therefore low temperatures and mechanical loads are not contradictory to CO₂-pellet application.

6.1.3 Influence on base materials

Due to the impact of the CO₂ particles damaging of surfaces has been observed.

- Al sheet material with thicknesses below .8 mm seems to be "hammered" after CO₂ pellet blasting.
 - Anodizing layers on clad aluminium show micro-ruptures and -fissures.
 - On composites microfissures can occur, uppermost layers can be delaminated, and copper filaments can be destroyed.
 - Coatings on backside of samples are removed.
- These effects may be excluded by a variation of the stripping parameters especially by reducing the pressure.

6.1.4 Economy

Because of the inverse proportionality of stripping rate and CO₂ consumption removal rates of less than 4 m²/h seem not acceptable from economical reasons.

On the other hand CO₂ pellet blasting may be a powerful tool because of its wide applicability also for cleaning purposes.

6.2 CO₂ pellet blasting in combination with flashlamp

Alternative to a pretreatment with chemicals radiation by flashlamps raises the effectivity of CO₂-pellet blasting. First experiments have been performed with a flashlamp / CO₂ facility at Maxwell Company (Ref 7) on 4 paint systems. While these paint systems needed very different reaction times with softeners, with the flashlamp/CO₂ combination same effectivities and stripping rates of about 1.6m²/h have been reached for these paint systems. At other paint systems maximum stripping rates of 4-5 m²/h have been obtained.

6.3 Laser application¹

Laser paint stripping allows a high degree of automation and is applicable for paint schemes and materials used in the aircraft industry. Reduction in maintenance time, minimum effort concerning material and manpower will result in economic advantage. Paint removal experiments have been performed at Dornier with different types of lasers (Excimer, CO₂, CO₂-TEA) concerning parameter variation, removal rates, influence to base materials, and gaseous waste analysis. This work will be continued in an BRITE-EURAM program with partners from 6 European countries, starting in 1993. Main tasks, studies and aims of this programme are overviewed in table 2.

¹This work was supported by the German MoD (BMVg) under contract No. E/B31E/L0113/L5104

Table 2: Overview on BRITE-EURAM laser paint stripping program

Main tasks	Studies	Aim
parameters, influence to base materials of different lasers	studied systems: Excimer-, CO ₂ -, Yag-Laser	optimized laser and its parameters
stripping of real components	different paint systems	paint removal studies, efficiency
concept of automation	Robot simulation, online and real time monitoring, image processing	Integration of laser and robot system
waste analysis	emission spectroscopy, mass spectroscopy, filter concepts	waste disposal concept
Feasibility study application to large 3-dim parts	computer simulation: plant layout, plant simulation performance analysis	

7. CONCLUSION

Comparing the paint removal methods described above we come to following result. Paint removal methods leaving only paints or their decomposition constituents are laser and flashlamp/CO₂ pellet application. Both are still in their infancy - at least in Germany. Application of softeners may bring problems if acid activated agents are used or high investments are needed to speed up non acid activated softeners by means of increased temperatures. Aqua jet and CO₂ pellet paint stripping need a chemical pretreatment of the paints with softeners with the implication given above. Plastic media stripping is up to now applicable for military aircrafts only. Therefore more developments - also with respect to paint composition - and comparative studies are necessary.

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THE DEVELOPMENT OF ALTERNATIVE PAINT REMOVAL TECHNIQUES IN THE RAF

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Summary

Personnel safety and environmental legislation is forcing the removal of chemical removers. The RAF chose the Plastic Media Stripping process as their alternative. During testing of the process a number of problem areas and additional advantages were highlighted. Solution to the problems are discussed and the advantages quantified.

INTRODUCTION

The RAF has been actively pursuing alternatives to chemical and laborious hand abrading paint stripping methods for the last 6 years. Over the latter 3 years legislation of the Health and Safety at Work Act and the Environmental Protection Act has put added impetus into this work. Several alternative processes were evaluated but after due consideration of the size of the RAF's problem, the

development potential and likely cost of the various processes, the Plastic Media Stripping (PMS) was selected as the process best suited to the RAF's needs and budget.

Although the PMS process offered elimination of chemical and vapour hazards and a significant reduction in the volume of toxic waste there were, in the early days, many reservations that the process would cause damage to sensitive aerospace substrate materials. To overcome these doubts the RAF placed great emphasis on this aspect and involved the Defence Research Agencies at Farnborough and Woolwich in all stages of the trials. It was also recognised that any damage to substrate materials in a production environment would most certainly cause a serious set-back to full scale introduction of the process, thus great emphasis was placed on the need

to instill confidence in the new process at every stage of development. Thus over the past 6 years, in addition to verifying the mechanics and structural integrity aspects of the process, the trial period was also used as an important public relations exercises to ensure that all aircraft and design authorities were kept updated at all stages.

TRIAL PROGRAMME

The first trials were set up at RAF St Athan in 1987 to assess the performance of PMS when removing selected surface finishes from a range of pre-prepared test panels and actual aircraft components. The effects of various medias, various media sizes and different operating pressures were measured. The trials were carried out in closed circuit cabinets and at the same time the opportunity was taken to compare the performance of 4 different cabinets including both wet and dry PMS systems.

MATERIALS USED:

- a. Aluminium alloy (LI56-T4).
- b. Alclad aluminium alloy (LI63-T3).
- c. Anodised li56 and li63.
- d. Cadmium plated steel.

Prior to stripping all the test panels were prepared to DTD 5580A specification (matt polyurethane) followed by age hardening in an oven at 75-80 degrees celsius. On completion of the paint stripping of each test panel, the structural effects were then studied by RAE Farnborough to determine:

a. Effects of PMS on the fatigue strength of various aluminium alloys. The effect on the fatigue properties were found to be negligible. In fact the cold working of the clad materials caused by the plastic media stripping produced an actual improvement in the fatigue properties.

b. Physical effects of PMS on the substrates of the different materials. Following PMS stripping, various degrees of disruption of the ALCLAD surface was found, however it was not removed and the clad layer still retained its protective properties. In practice the disruption caused is much less than that found on aircraft which have been stripped previously with chemicals. The damage to unclad anodised test panels, were found to vary according to the method of anodising. There was for example no noticeable effect on sulphuric acid anodising surfaces, but chromic acid anodise was shown to be susceptible to chipping, with the severity of chipping being related directly to the coarseness of the plastic media particles and to pressure used. However, damage caused by 40/60 grade media at 15 psi being negligible.

c. The effect on the anti-corrosive properties of anodised and cadmium plated corrosion resistant finishes for aluminium and mild steel. Accelerated corrosion tests to assess any degradation of protection was achieved by immersing the stripped test panels for 21 days in a sodium chloride solution and a neutral salt fog test as set out in British Standard 5466. The results showed that the dry stripped panels retained their excellent corrosion performance, but in contrast those stripped by the wet process showed signs of plating breakdown and corrosion. This was particularly severe on the cadmium plated steel.

The results of these extensive trials, which took some 9 months to complete, provided the necessary confidence to invest in the PMS dry stripping process, and to adopt it as an acceptable replacement for chemical stripping. However, it was recognised that actual stripping parameters would have to be clearly established and strictly adhered to for each type of material and when scaled up to whole aircraft stripping, a complete skin map for each individual aircraft would be essential prior to commencing any stripping. The decision was made at this time to adopt the dry rather than wet PMS process. The trials had shown that advantages offered by the cushioning effect of the water was outweighed by the much higher operating pressures which restricted stripping to relatively thick substrates. The wet system had also demonstrated the accelerated corrosion problem. However more suitable applications have since been recognised for the wet process. Wet cabinets are now being successfully employed for the paint stripping of aircraft wheels and mechanical components, where water acts as a de-greasing additive, allowing both degreasing and stripping to be achieved at the same time; lower operating pressures permit degreasing alone.

EQUIPMENT TYPES

The need was also recognised for a number of different forms of PMS facilities to cope with the various types and sizes of equipments requiring to be stripped. The decision was therefore made to provide the following systems:

a. Closed Circuit Cabinet. Of a size approximately 1 cubic metre suitable to take the smaller aircraft structural components. The main features being:

- (1) Loading platform with rotary table.
- (2) Automatic media recovery and reclamation.

- (3) Air blast to remove media from workpiece.
- (4) No personal protection equipment required for the operator.

23 of these cabinets are now in operation at RAF units throughout the UK and Germany.

b. Booth. Booths can be of any size to suit the task. Ours have been designed to take the larger type aircraft structural components. The main features incorporating:

- (1) Partial floor recovery system.
- (2) Twin nozzles from independent pressure vessels providing a degree of redundancy.
- (3) Ventilation system to control dust levels.
- (4) Separately supplied breathing air systems.

These booths are being provided in 2 different configurations. Firstly, as a permanent stand alone external building now in operation at RAF St Athan. Secondly, as a self contained booth for use inside an existing building, which are about to be installed at RAF Kinloss and Lyneham.

Tent Configuration

To satisfy partial paint stripping requirements and to enable the task to be carried out in a normal engineering production environment with the minimum of disruption, the creation of a temporary tented enclosure around the area of the aircraft to be stripped has certain attractions. Using a suitable mobile PMS plant, a mobile air extraction unit and suitable tent configurations, a safe Plastic Media Stripping environment can be formed very quickly, around an aircraft or part of the aircraft in a maintenance hangar. Such a

configuration enables the normal engineering activities to continue on the aircraft whilst the stripping process is operating within the tented area.

Complete Aircraft Facility

Being realistic it has always been accepted that the RAF complete aircraft stripping facility would most certainly be restricted to the fixed wing fighter and certain rotary wing size aircraft. In this context a twin fighter sized Plastic Media Stripping facility is planned to be operational within the next 2 years. To date we have completed trial PMS strips of 2 Hawk and 1 Hunter aircraft and learnt many valuable lessons. The most important lesson learnt to date is that the need for effective masking to prevent ingress of media will be the most difficult and important task to achieve in the production process.

OTHER BENEFITS

The decision to adopt PMS soon showed that many other important benefits could be realised provided that a number of practical problems could be overcome. These benefits are:

a. Operator acceptance. Men who had previously used chemicals for stripping have readily and enthusiastically accepted the new process. The safer and quicker way of working gave an improved work rate, greater interest in the task and a significant improvement in morale. It was also learnt that the process could be enhanced and improved by close co-operation between the workforce and the project engineer. For example, the initial break through of a coating can be achieved more quickly by reducing the stand-off distance until the surface begins to break before reverting to the standard distance set for the job.

b. Improved efficiency. Cabinet performance is relatively easy to check. In all

applications it was demonstrated that individual components could be stripped saving 50-60% in process time compared to chemical stripping. However as the operator is continually occupied when dry stripping, only about 10% of operator time is saved in batch work. Similar output savings have been obtained in booth operations but, for complicated items the requirement for degreasing, masking and removing media after stripping tends to reduce the overall efficiency as ways of improving techniques for degreasing and masking have not yet been developed, nevertheless TRTs have all shown 30% or more improvement. We are not yet qualified to pronounce on the efficiency of full aircraft stripping but our trial results showed that less than 100 nozzle hours were required to fully strip a Hawk aircraft in less than ideal trial conditions. The USAF have much more validated data on this subject and there is no reason to doubt that similar efficiencies will be found in aircraft sized facilities as in cabinets and booths. Input savings in our small scale operations have been difficult to quantify. Certainly at the moment in UK, media is more expensive than chemicals, but this may not always be the case as the tendency is for media prices to fall and chemical prices to rise. On a practical note, when media in an aircraft component facility reaches the end of its useful life, it can be removed and collected for use a second time at higher pressures in a less critical situation such as stripping ground support equipment, where it is particularly effective for removing paint from tubular steps and access equipment, eg RAF safety raisers can be stripped in one 8-hour shift in comparison to the 8 shifts required for chemical/hand abrading methods.

c. Reduced Waste Disposal Costs. Waste disposal costs are escalating throughout the community. PMS offers significant reductions on this overhead. The machines by their very nature concentrate the toxic elements of waste in their dust collectors. Collection is simple and volume is reduced to about 1/6 of that generated by chemical methods giving a similar reduction in waste removal costs.

d. Versatility. Recognising that a booth can be of almost any shape or size, a number of mobile PMS equipments were purchased to use with a mobile compressor and a mobile air extraction machine. This combination can be used almost anywhere where the media can be contained. Suitable enclosures range from rooms, hangars, tents and sheeted enclosures around aircraft and indeed spaces within aircraft themselves. However in general media recovery has to be achieved by manual sweeping. It is in these situations where the cleanliness of the process comes to the forefront. The toxic vapour hazard associated with chemicals is eliminated and, provided the dust hazard can be contained, PMS can be used within the maintenance hangar and alongside other workers eg. In Tornado engine air intakes. The solution to the Tornado intake problem was especially simple and neat; the intake itself acts as the booth and a fabric sock with vents to collect media and to extract air and dust is fitted over the end of the intake to give a safe clean environment. Additionally the machine itself is totally pneumatic powered and presents no electric spark hazard in the working area. Similarly pressure bulkheads and undercarriage bays have been stripped with these PMS machines.

e. Trials Potential. Another advantage of these portable

machines is their small media capacity, allowing the type of media to be readily changed. This feature has allowed tests to be carried out under production or workshop conditions. Two machines are now being used to determine how best to remove paints from composites; in particular from Harrier GR5 (AV8b) components. The results are extremely promising and we expect to present the results to the aircraft design authorities in the near future with the aim of obtaining clearance to strip whole aircraft. Most harder composites can be stripped with the exception of foam filled light GRP sandwich fairings and radomes, which so far have defied all attempts to find a suitable media. All our trials on composites have shown that the stripping task would be much easier and would provide wider operating margins for the operator, if a marker coat was applied before any refinishing took place. Our research agencies have been tasked to develop a hard, lightweight and brightly coloured (pink) coating for this purpose so that operators can easily see when all topcoats are removed and by leaving the thin pink film demonstrate that the substrate integrity is not compromised.

f. Reliable and Available Machinery. Shot or grit blasting has been used for 100 years or more and during that time the machinery has developed so that the principles of operation construction and reliability are well understood and in general confidence can be placed in the hardware.

PROBLEMS ENCOUNTERED

The application of an essentially simple process to aerospace use where substrate integrity is of prime importance and where the choice of media and operating parameters is critical is not generally understood

by shot or grit blasting experts they are astounded by the slow stripping speed accepted by the PMS operators, but what they do not appreciate is the slow cumbersome and hazardous chemical method it replaced. Once it has been realised that PMS is an entirely new or different process to shot blasting then the problems encountered can be put into perspective. These problems are all related to process control which became very apparent during the trials in cabinets and on the Hawk aircraft. These are their solutions are discussed below.

Process Control. Process control is vital to avoid the potential for damage to substrates. Operating parameters and the type and quality of media need to be carefully chosen and proven for each new substrate to ensure that the operator is given the greatest range of operating margins. There are many variables, but because it is generally a laborious job to change media, especially in large machines it is most practical and economical to keep this variable constant and to carry out small scale tests on each new substrate to determine the optimum parameters to give the best strip rate without damage. For the general range of aerospace materials ALCLADS, and aluminium alloys, the type V thermoplastic acrylic has the best economic advantage. In the early days of our PMS operations, the lowest combination of parameters suitable for the softest substrate - ALCLAD - were authorised for work on all substrates having a skin thickness greater than 32 thousand. As experience was gained, these parameters were increased to obtain greater stripping rates for thicker, stronger materials. For some composites, other medias such as type 6 (poly carbonates), wheat starch and sodium bicarbonates may be required to achieve satisfactory stripping.

The correct combination of all variables need to be recorded in a process document for each task. Acceptance, certification and authorisation of such process documents is initially a long

laborious task, particularly when marketing the process to design authorities in the first instance. Notwithstanding the presence of a process document there are variables which cannot be forecast, the paint thickness and type may have changed by repair, hardness/brittleness may vary because of degree of aging. Thus speed and effectiveness of stripping is very much operator dependent, and it follows therefore that operators need to be specially trained and selected.

Operator Selection and Training. PMS is well described as "paint spraying in reverse". Men trained to spray paint, quickly demonstrated the difference between stripping and blasting showing that they can consistently remove paint much quicker than non-painter operators. The resulting quality was also much better because painters are aware of the standard of substrate preparation needed for easy paint application and high quality finish. Consequently the decision was made to select PMS operators from the surface finish trade only.

Training. Training of these men, the painters, was therefore, simplified in the practical skill of hand phase, and was concentrated on:

- a. An appreciation of the effects of PMS of various substrates.
- b. The choice of media and operating parameters.
- c. Identification of substrates in conjunction with airframe specialists.
- d. Methods of masking to prevent media ingress.
- e. Care and maintenance of the equipment.

Supervision. The task is tedious and continuous supervision is required as operator concentration tends to slip and stand off distances vary. We believe that a practical limit for

continuous working is about 30 mins. As an additional safeguard our installations are equipped with remote override controls for the supervisor to halt stripping as required. Operators quickly learn that stripping rates are directly proportional to the operating pressure, but so is the likelihood of damage, thus control of stripping pressure is given only to the supervisor through lockable pressure control valves.

SKIN MAPPING

On complex components a system of marking the various substrates has been developed. This permits supervisors to vary stripping parameters to obtain the best stripping rates without compromising the integrity of various substrates. In some cases a simple go/no go masking procedure is adequate, in others colour marking so that hardest and heaviest substrates can be stripped first.

CONTROL OF MEDIA INGRESS

By far the largest production problem is control of media ingress, obviously flat panels, removed components, and items without complex internal parts have little or no problem from media ingress but as size and complexity increase so does the problem of ingress. The worst case is likely to be a military aircraft flown into a facility for external paint replacement. Every single aperture, of which there are many of varying shapes and sizes will need to be meticulously sealed to a greater degree than that required for chemicals. A multitude of methods are used, restricted only by the imagination of the process controller. Hot melt glue is used to seal and protect joints, plasticine and polythene bags under opening panels, bungs and blanks as required and a special resilient abrasion resistant tape. For repetitive tasks we envisage a full check list and full set of masking blanks to be completely fitted before beginning stripping.

QUALITY CONTROL

Because the process is operator sensitive and has a considerable number of variable parameters, several measures of quality control have been found to be necessary.

- a. Process Documentation. Each task needs to be defined and at a minimum should define the type and thickness of substrate, the authorised media(s), and associated operating parameters; and where necessary, the masking requirements and the checks for media ingress after job completion.
- b. Equipment checks. Initial and periodic checks of nozzle pressure is essential.
- c. Substrate checks. Are perhaps the most difficult to define. We have selected a simple surface roughness check and have found that an RA of less than 6 microns for ALCLAD and RA less than 4 microns for harder alloys is a practical limit. For castings and certain plates, the allowable roughness specified on the manufacturing drawing is taken as the control.
- d. Media check. Quality control of media is essential both during the purchasing cycle and during operation. Any of the deviation from specification can render the media dangerous to the substrate or uneconomic particularly if there are too many fine particle which represent an immediate waste.
- e. End of process check. The final quality control is to remove all masking and to check and remove any media ingress that may have occurred.

COLLABORATION

Throughout the whole period of our work to date to find safer and more acceptable alternative methods of paint removal, excellent support has been provided by specialist companies

within the UK, such as Vacublast International, AST Group - International Dry Stripping (previously known as GPA, Express Air) and, Hodge Clemco. We have also tried to keep in close contact with developments in other countries particularly the USA, France, Holland and Germany. The lead taken within the USA on Plastic Media Stripping and on the development of other techniques such as cryogenics, sodium bicarbonate, and lasers etc, is much appreciated. Their work enabled the RAF to make the decision in favour of the Plastic Media process. PMS was seen as a system that could be implemented fairly quickly with the minimum of risk, but more importantly would provide a process offering the flexibility necessary to strip the smallest component and the whole aircraft at the minimum cost.

Another recent visit which proved to be extremely valuable was to the euro refurbishing centre at Rodez in Southern France, which has a large aircraft hangar incorporating a dual function 8 nozzle Plastic Media drying stripping and paint spraying facility in operation. The funding of which it is understood was a shared venture between the EEC and the french government.

Finally, although out paint removal problems in the UK are minuscule compared with those in the USA, the opportunities offered by the Joint Department of Defence and Industry Advanced Coatings Removal Conference held annually in the US, and this particular NATO forum are extremely important to discuss and exchange information on this important subject of alternative paint removal methods.

FUTURE PLANS

The RAF's most important objectives are to:

- a. Continue marketing and promoting the PMS process.
- b. To develop and commission the training facility from our operators and superiors.

c. Install and commission the full aircraft facility at RAF St Athan.

Through these initiatives the UK, in particular the RAF, will reach its twin objectives to introduce a more environmentally friendly and a more efficient and safer paint stripping process. A further purchase of equipment, predominately booths, for more Air Force units will be made, as funds allow, to extend the process into paint stripping ground equipment and vehicles with PMS.

"Operational Aspects of F.16 Plastic Media Blasting, as Carried out by Fokker Aircraft Services".

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1. ABSTRACT

In 1987, Fokker Aircraft Services started F.16 air-intake paint removal by means of Plastic Media Blasting (PMB). Especially for this process, a robot has been developed. In a later stage, complete exterior PMB-paint removal has been tested and successfully adopted. The paint removal is carried out in the scope of a thorough corrosion control program. The requirement that all the paint must be removed in order to allow this control program to be carried out properly, leads to severe masking complications.

The process parameters are relatively conservative, because of the requirement that absolutely no anodic layer damage is permitted. Following PMB paint removal, corrosion is removed using aluminium oxide blasting. Finally, a highly flexible polyurethane paint system is applied, based upon TT-P-2760 Koroflex primer.

To summarize the process, it can be stated that the plastic media blasting itself is straightforward. Proper masking is difficult to perform though, compounded by special customer requirements such as open panel edges.

2. HISTORY

Fokker Aircraft Services (FAS) has been involved in PMB since 1986, when the first careful trials hinted that this process would be ideal for removing paint from thick-skin substrates.

At about the same time, the RNethAF became interested in removing paint from the engine air-intake as part of a retro-fit modification. Because the air-intake borders many

inaccessible areas of the airframe, the use of liquid paintstrippers was considered unacceptable. Any leakage through gaps and countersinks etc. could lead to severe hidden corrosion.

Alternatives were sanding and PMB. Sanding was unacceptable for economic reasons, leaving PMB as a little known, but very promising process.

Meanwhile, in 1987, FAS carried out a series of tests, leading to the conclusion that non-clad, anodised skins could be safely blasted up to five times, without adverse effect on the anodic layer, using the PolyPlus 40-60 media. Unfortunately, Alclad-anodised skins could not be blasted without completely destroying the anodic layer.

The first F.16 engine air-intake was manually blasted by FAS, with excellent results, in 1987. To further increase the process economics, a robot, tailored to the air-intake, was developed by Schlick to FAS-specifications. This reduced the blasting of the air-intake to a 22 hour, one-man operation.

In 1988, it became apparent that the whole RNethAF F.16-fleet needed a complete "bare-skin" corrosion inspection. The aircraft needing this most urgently (F.104 and NF.5 corrosion problems being vividly remembered) were taken on as trial aircraft almost immediately. Of these few aircraft, only the wing bottom skins and air-intake outer surfaces were blasted.

These being trial-aircraft anyway, several paint systems were tried, following the PMB. Additionally, cold-flexibility and corrosion protection tests were carried out by the Netherlands Aerospace Laboratories (NLR). This led to the conclusion that a paint system

consisting of Alodine, Koroflex primer and Aerodur HFA topcoat performed best.

Today, FAS applies PMB, corrosion blasting and re-painting to F.16's on a routine basis. The process as laid down in our own process-standards is not a copy of the standards laid down in the USAF T.O.'s, differing at several points, discussed hereafter.

3. PROCESS STARTING POINTS

PMB to F.16 surfaces in the past has learned that any anodic layer gives excellent corrosion protection. Whenever this anodic layer is broken (panel edges, rivet countersinks, impact damage etc.) corrosion will sooner or later occur. This has led to the RNethAF's statement that the anodic layer must not be damaged in any way by the paint removal process, and that all security measures must be taken in order to reduce the risk of damage to an absolute minimum.

In order to be able to inspect the aircraft metal structure thoroughly, all paint must be removed, including from the extremes of panel edges etc., as this is one of the places where corrosion is frequently found. This means that external masking of hinged panels is not possible. The more labourious internal masking has therefore been adopted.

Corrosion removal must be done very accurately, since leaving corrosion behind will render the whole process pointless. The only practical way to ensure complete corrosion removal is the technique of aluminium-oxide blasting. Any sanding or grinding technique will merely move the corrosion around, or cover it. Additionally, the damage tolerance of the wing bottom skin is too easily exceeded using powered grinding tools.

Adopting the DeSoto Koroflex primer has introduced one more point of attention to the process, because this primer, being polyurethane instead of epoxy, is very sensitive to the cleanliness of the surface it is applied to. This has led to a stringent quality control of the surface prior to chromate coating and priming, including a careful waterbreak test of the entire surface. Cleaning is done with alkaline detergent, assisted by MEK only on the most recalcitrant of water-break indications.

4. THE AIRCRAFT

The F.16A and B aircraft, as used by the RNethAF, have been painted with a system consisting of MIL-P-85582 epoxy primer and MIL-C-83286 High-Flexibility polyurethane matt topcoat. The stiffness of the primer leads to cracking of the entire paint system in areas where structure movement is relatively high. Especially paint cracking around fasteners is often seen.

Corrosion is usually found on locations such as skin seams in the air-intake and in the pylon-areas of the wing bottom skin. Notorious are the fuel tank sealant injector inserts which cause corrosion in the surrounding wing bottom skin. The corrosion type is predominantly pitting.

5. PREPARATIONS FOR PMB

Upon arrival, the aircraft is washed with an alkaline detergent MIL-C-87936 type 1. Excessive grease is removed using aliphatic naphta. Following this, a number of components is removed from the aircraft, including the engine, canopy, engine-to-fuselage fairing, landing gear doors and launchers. Electronic units and hydraulic actuators in the fuselage are carefully wrapped in polyethylene sheeting, before the corresponding panels are masked and closed. Typically, the "form-in-place gasket" prevents dust and media ingress. This requires additional masking of latches and hinges, which is done with a combination of polyethylene sheeting, vacuum-bag tape, linnen heavy-duty tape and hot-glue. Care is taken to leave the gap between panels open. On a few locations, internal masking is not possible. Here, seams and hinges are masked externally with Scotch blasting tape. Paint is later carefully sanded down to the primer layer.

6 PAINT REMOVAL

First, the engine air intake is blasted using the specially developed robot. A tubular adaptor, housing the robot, is mounted in the engine supports. A dust and media collector vessel is mounted on the front opening of the intake. In this way, a completely enclosed chamber is obtained, in which the blasting takes place as in a blasting cabinet. The robot moves back and forth in the air-intake, adapting itself continuously to the varying cross-section. On

each track of the robot, a width of approximately 200 mm is blasted clean. An operator, observing the process through windows in the rear and the front, controls blasting parameters and robot movement. Later the outside surface of the aircraft, minus composites, is blasted manually, using two nozzles.

The blasting parameters are rather conservative: media used is the 3.5 MOH thermoset type II, of size 40-60. Nozzle pressure is between 20 and 30 PSI, while the nozzle angle is between 0° and 30°. Testing has shown this to be the safest option (anodic layer-wise) that results in a reasonable strip rate.

An attempt has been made to replace the thermoset type II media with thermoplastic type V. Remarkably though, the latter left a yellow primer residue on the surface. As this conflicted with the demand for complete paint removal, it left no choice but to return to the type II.

7. CORROSION REMOVAL

Following the PMB process, the bare skin is inspected for corrosion. Any corrosion found is removed using aluminium-oxyde blasting with an enclosed-nozzle system. The aggressive aluminium-oxyde media has shown really to remove the corrosion, whereas the more popular glass-bead tends to merely deform the surface while covering the corrosion with fresh metal. In this stage, it is demonstrated that corrosion rarely occurs without the presence of a galvanic element such as a steel fastener or insert, and equally rarely on locations with a perfect anodic layer.

Spots that are blasted this way, obviously at the cost of the anodic layer, are immediately chromate treated.

8. CHROMATE TREATMENT

The Alodine chromate conversion coating has shown to be an excellent basis for the paint system applied later.

Prior to the application of the Alodine, the surface is cleaned using an alkaline detergent. The cold detergent is carefully agitated with ScotchBrite.

After a contact-time of 10 minutes, the whole aircraft is lavishly rinsed, followed by a second rinse with demineralised water. This step also acts as the water-break test for surface quality.

Contaminations which have not been removed by the detergent, indicated by the water-break, are removed by a local MEK solvent wipe. This is followed by another detergent-application after which the surface is considered to be clean. Sometimes waterbreak is caused by surface stresses and tensions often seen on strongly curved surfaces. With this in mind, no second waterbreak-test is carried out. Without allowing the surface to dry, the application of Alodine is carried out. The normal application procedure requires a careful rinse after the application-time, which means the aircraft is hosed down a second time.

9. PRIMER APPLICATION

Being of a polyurethane nature, the Koroflex primer requires a careful control of air-humidity.

Depending on other work to be carried out on the aircraft, the primer is applied in one or two steps. If the latter is the case, the first layer is reactivated with MEK before the second is applied.

10. TOPCOAT APPLICATIONS

The application of the matt polyurethane topcoat requires no special techniques. In order to judge the quality of the paint system as a whole, a number of tests are carried out, including wet and dry adhesion, thickness and gloss.

11. RESIDUE

It is not possible to apply PMB on a fighter aircraft without ingress of dust and media. This is obviously enhanced by the requirement that during blasting, cleaning, chromate coating and painting as many seams and edges as possible must be open to be processed.

This means that after the PMB the masking of critical areas is removed, in order to allow a thorough cleaning of the interior. Before the "wet" processes, this masking must, of course, be re-applied.

Use of robots for aircraft dry stripping via plastic media blasting

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SUMMARY

In order to meet constant financial and reliability concerns, European manufacturers have introduced more and more composite materials on their aircraft. In addition to failings for which the use of composites has become absolutely necessary, composites are used on each new programme for structures which are more and more highly loaded and sophisticated.

Similar to metallic structures, an external paint scheme is applied to these composite structures to protect them from ultra violet rays, provide general corrosion resistance and allow the airlines to customize their aircraft.

Conventional stripping methods using chemical strippers cannot be used as many impregnation resins do not resist chemical strippers. Aérospatiale have endeavoured to find new efficient methods that are easy to implement, cause no damage and are applicable both to metallic and composite structures.

Dry stripping via plastic media blasting has formed the subject of many tests.

These tests proved that such stripping was compatible with the objectives but required automation of the process for large airframe stripping.

Aérospatiale have monitored the work performed in this field: Process which are now considered to be industrial has been tested on an airframe on June 1992.

Numerous aircraft undergo a through cleaning operation each year.

This is required for:

maintenance reasons
safety reasons, or simply for design reasons.
This work involves stripping off the exterior paint of these aircraft, and then repainting them.

Airbus Industrie and Aérospatiale are under the obligation to provide airlines with a paint removal system.

These airlines' requirements have enabled Aérospatiale to draw up specifications and process.

This process must offer the following major advantages:

Process applicable to all substrates
Rapid implementation
Competitive industrial application
It must be a low-toxicity process for environmental and work hygiene reasons.
Finally it must permit direct repainting.

Three types of operation are performed:

- removal and surface preparation on elementary removable parts, either metallic or composite parts
- sometimes the removal and surface preparation involves aircraft sections.
- finally, the same operations are carried out on very large surfaces, such as the fuselage, prior to the application of new exterior paint to give aircraft a new look.

At present, several processes are used:

Chemical
Sanding
AquaStrip
Duplex PMB
CO2/ice
DMB

From the very beginning industrialists have implemented chemical and sanding procedures.

Though still used nowadays, they are no longer competitive, they cause composite materials to deteriorate, they limit productivity and, moreover, have aroused controversy with regard to hygiene and safety.

The most recent processes: AquaStrip, Duplex PMB, CO2/ice have not been retained (appendix 1).

A comparative study carried out by Aérospatiale has pointed out problems of material compatibility, productivity, hygiene, and safety.

In economic terms, these new procedures, which are still at the prototype stage, would require too great a financial investment for an industrial application.

The solution retained was Dry Media Blasting, or DMB.

Whatever its application, removal or surface preparation, this procedure, in its robotized phase, increases productivity, reduces cycles by eliminating a number of highly qualified staff, and finally, meets the most stringent hygiene and safety requirements.

DMB (Dry Media Blasting) involves projecting plastic or plant based particles - the Media - by compressed air.

The first feasibility test was performed in 1985, and has now been qualified by all aircraft manufacturers. Since the first application, numerous industrialists have worked on robotizing the DMB process, notably the Canadian company and Aérospatiale partner Compustrip (appendix 2).

Blasting and possible robotization had to be experienced on aircraft airframes (appendix 3).

This aim was reached. Compustrip robot correctly moved around the aircraft, the blasting operation was reported to be satisfactory (adequate roughness).

This robot should however be optimized:

- need for dustproof blastingbox
- productivity improvement

These criteria have been taken into account and could be resolved with an industrial approach.

This experimentation will be completed early next year, on the same airframe, but with a complementary robotic from Schlick society.

PROCESSES

PROCESSES	DEFINITION	BACKGROUND		
		80	85	90
CHEMICAL STRIPPING	Action of aggressive chemical stripping agents followed by manual mechanical scraping.			
SANDING	Rotating sanders fitted with abrasive discs (dry sanding or sanding using solvent).			
AQUASTRIP	Action of chemical denaturing agents followed by projection of water under pressure (300/500 bars).			
DUPLEX FMB	Plastic media blasting combined with a 60° C chemical denaturing agent jet.			
CO2/ICE	Action of a chemical denaturing agent followed by solid CO2 or ice blasting.			
DMB	Plastic or vegetable media blasting.			

Appendix 1/1

	CHEMICAL STRIPPING	SANDING	AQUASTRIP	DUPLEX PMB	CO2/ICE	DMB
PRODUCTIVITY	..	...	+++	..	..	+(?)
SANITATION AND SAFETY	...	+	-(?)	.	.	+++
SELECTIVITY	...	+++	0	0 (?)	0	+++
COMPATIBILITY	...	+++	0	0	0 (?)	+++
COST OF RAW MATERIALS	0	+	+	..	0	..
DAMAGE	0	..	... (?)	-(?)	0	++
INVESTMENT	0	.	..	-	..	...
IMPLEMENTATION PARAMETERS	++	++	..	0	0	0
IMPLEMENTATION FLEXIBILITY	-	++	..	..	..	..

Appendix 1/2

STRIPPING

PROCESSES	ADVANTAGES	DISADVANTAGES
CHEMICAL STRIPPING	Known process / qualified on metallic components	Not industrial / contaminating / compatibility / long cycle / sanitation and safety
SANDING	Compatible with all substrates Qualified on aircraft airframes	Long process / fluid projection / deposit on discs / surface appearance
AQUASTRIP	Productivity	High pressure / water ingress / sanitation and safety / compatibility
DUPLEX PMB	Removal of sealants (Repair)	Compatibility * / used at high temperature / productivity / sanitation and safety
CO2/ICE	Cost of media (3F/kg) / selective	Not industrial / productivity / compatibility / sanitation and safety
DMB	Dry stripping / compatible / selective / not contaminating / industrial	Cost of media (25F/kg) Investment

(*) being checked

Appendix 1/3

COMPUSTRIP VR-3000 SERIES

DESCRIPTION

AUTOMATED, DUST-FREE, MEDIA-BLAST PAINT REMOVAL SYSTEM FOR TRANSPORT-SIZE AIRCRAFT.

PRINCIPLE OF OPERATION

THE OPERATOR WILL POSITION THE SYSTEM TO ACCESS A SPECIFIC SURFACE-AREA OF THE AIRCRAFT.

THE SELECTED AREA WILL BE STRIPPED IN A FULLY-AUTOMATED MODE, USING PRE-PROGRAMMED PARAMETERS.

DURING THE AUTOMATED PAINT-REMOVAL OPERATION THE OPERATOR.

MONITORS PAINT-REMOVAL RESULT AND ADJUSTS DWELL-TIME (end-effector travel-speed) AS REQUIRED, IN REAL-TIME (video assisted)

REACTS TO SYSTEM MALFUNCTION DIAGNOSTIC DATA PROVIDED AT HIS CONTROL STATION.

UPON COMPLETION OF THE AUTOMATED PAINT-REMOVAL OPERATION, THE OPERATOR REPOSITIONS THE SYSTEM TO ACCESS THE NEXT AIRCRAFT PANEL/SECTION.

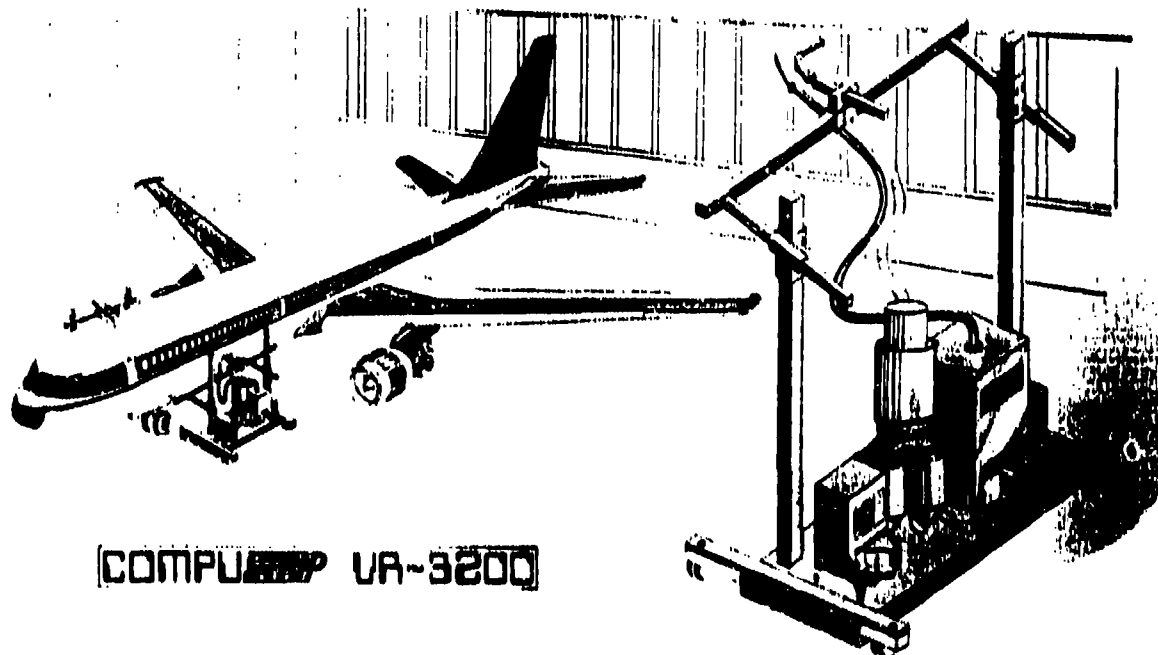
Appendix 2/1

COMPUSTRIP VR-3000 SERIES

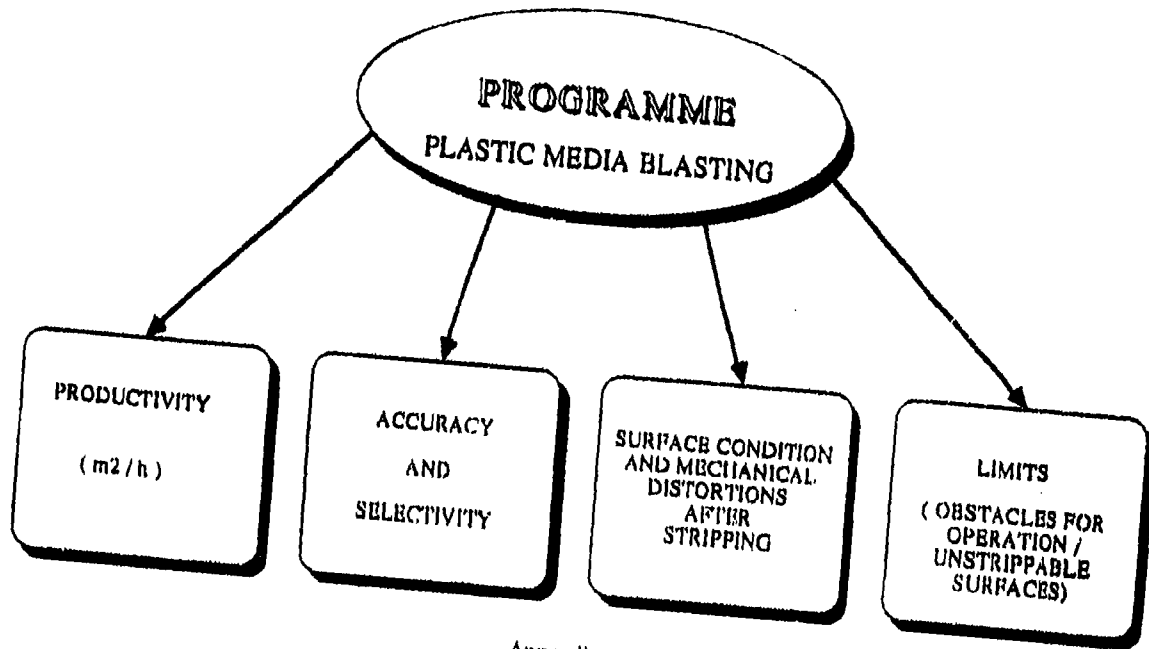
MAJOR FEATURES

- . MOBILE
- . SIDE-GANTRY TYPE
- . SINGLE-CAR AND TWO-CAR OPTIONS
- . ELECTRIC DRIVES
- . MODULAR
- . SEMI-AUTOMATIC:
 - . FULLY-AUTOMATED PAINT-REMOVAL OPERATION
 - . SYSTEM POSITIONING BY MANUAL CONTROL
- . SIMPLE X,Y, AXIS (ONLY) MOTION PROGRAMMING
(sensor-based adaptability in real-time to airframe curvature)
- . CLOSED-CYCLE MEDIA BLAST/RECLAIM
- . MULTI-NOZZLE CAPABILITY
- . PROCESS PARAMETERS ARE PROGRAMMABLE AND COMPUTER CONTROLLED (nozzle angle and distance are changed manually)
- . DWELL-TIME ADJUSTABLE IN REAL-TIME BY OPERATOR (video assisted)
- . MULTI-PROCESS COMPATIBILITY

Appendix 2/2

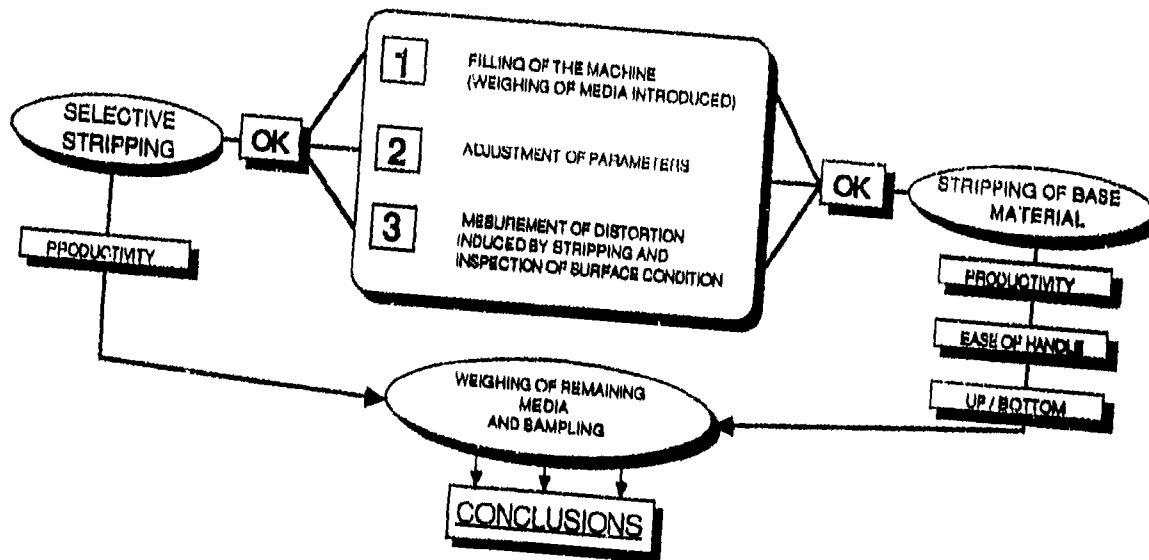


Appendix 2/3



Appendix 3/1

TESTS



Appendix 3/2

DEMONSTRATION ON TRANSALL

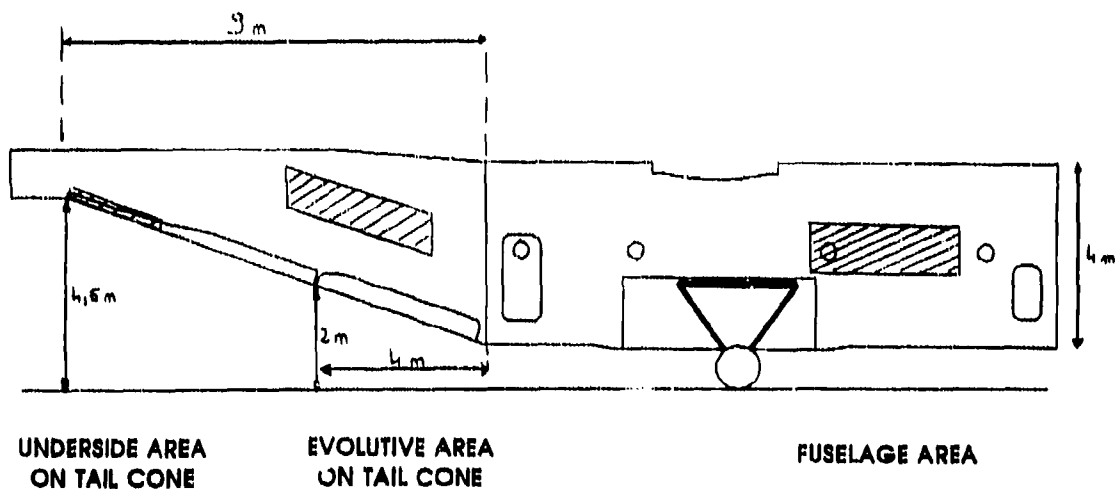
Aim: To validate plastic or vegetable media blasting robotization on an airframe representative of the aircraft (Transall).

FACILITIES: Use of one type of robot on the Toulouse site (AMD / BA hangar)

- COMPUSTRIP (Canada)

Appendix 3/3

PAINT STRIPPING DEMONSTRATION Presentation of the jobs



Appendix 3/4

GERMAN AIR FORCES EXPERIENCES WITH PLASTIC MEDIA BLASTING AND FUTURE REQUIREMENTS

by

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Key Words: Aircraft Maintenance, Paint Stripping, Stripping Facilities,
Plastic Media Blasting, Composite Materials

ABSTRACT

German Air Force (GAF) has been researching on a method of paint removal for a couple of years to replace the chemical method still in use.

This is to improve corrosion prevention, environmental protection and health care.

With the support of German aerospace company MBB and the University of the Armed Forces in Munich GAF selected Plastic Media Blasting (PMB) as the most suitable method.

Having a stripping facility for the entire aircraft at MBB Manching already in existence, GAF decided that the next step forward to gain more experiences is to establish a smaller "stripping cabin" at an air force base. This cabin is suitable for stripping removable parts and components of aircraft and equipment with the max. size of a half dismantled TORNADO wing.

With these gained experiences GAF will be in position to formulate the specific requirements for an entire on-base aircraft stripping plant which will be suitable for F-4s, TORNADOs and EFAs, too.

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2. Plastic Media Blasting (PMB) and Alternative Methods
3. Scientific Investigations for Certification
4. Plastic Media Blasting Facilities in Germany
5. Experiences with the Small Plastic Media Blasting Cabin
6. Future Requirements

LIST OF FIGURES

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2. Stripping methods
3. PMB system and its components
4. PMB pellet cycle
5. Investigations for Certification
6. Test arrangement
7. Abrasive effects of PMB
8. Impacts of hardness probe
9. PMB facilities in Germany
10. The small PMB cabin
11. Stripping crew at work
12. Stripped aircraft parts and components
13. PMB facility for the entire aircraft

1. INTRODUCTION

Stripping an aircraft, i.e. paint removal, is a regular event and part of an aircraft maintenance program.

The requirements are (fig. 1):

- dismantling of corrosion,
- treatment of corrosion,
- replacement of the corrosion prevention primer.

The last requirement (replacement of the primer) has not yet been implemented by German Air Force (GAF), because until now stripping an aircraft only includes removing of the upper layers of paint. Removing and replacing also the primer is indeed much more helpful for corrosion prevention, because the primer loses its active corrosion protection capability after about five years of age or application. This is the main technical aspect why GAF wanted to introduce a new more effective stripping system. The second aspect is that the new system should comply with the environmental protection and health care regulations of today. The third aspect is, that the new system should be adaptable to strip modern materials as reinforced glass fibers or carbon fibers without harming them. For example the surface of the European Fighter Aircraft EFA is covered with up to 70% of Carbon Fiber Composites (CFC). The evaluation process of finding a new stripping system had to consider all three of these aspects equally.

2. PLASTIC MEDIA BLASTING (PMB) AND ALTERNATIVE METHODS

Today there are several different methods available for the above mentioned purpose. They all intend to replace the traditional chemical way of stripping an aircraft or parts of it.

The alternative methods are (fig. 2):

- use of abrasives,
- laser energy,
- high pressure water blasting,
- glass pearls blasting,
- carbon dioxide pellets blasting,
- plastic media blasting.

And more methods are expected to appear in the future.

Plastic Media Blasting (PMB) is more or less an abrasive method, which uses small plastic pellets with different kind of hardness to remove one or more layers of paint in one working cycle. High pressure air is used to accelerate and blast the plastic pellets through a nozzle towards the treated surface. Different air pressure, variable quantity of pellets per air volume, certain distance and angle to the treated surface are the parameters by which the stripping result can be influenced. They can be chosen individually to suit best the stripping requirements as kind and thickness of the material and thickness of the layers of paint. This is called "parameter stripping". A general description of the PMB stripping process is given in figure 3.

However the following three effects will appear, when a plastic pellet hits the treated surface:

- the paint will be abraded,
- a percentage of the pellets will be damaged,
- the surface material will be more or less damaged.

The severest effect which may occur is of course the destruction of the surface material. This means that the blast of pellets will really shoot a hole into the aircraft material. This event is quite normal for thin aircraft sheets, as for example used in general aviation aircraft.

A point to mention is that the workers need to wear dust masks while stripping, because in spite of an exhausting facility directly connected to the stripping nozzle some dust can't be avoided.

An advantage of PMB is, that the exhausted dust contains a mixture of particles of paint, destroyed and undestroyed pellets and that a percentage of undestroyed pellets can be regained. These pellets will be fed back into the pellet container and will be used again. This is the so called pellet cycle (fig. 4) which is of course cost effective.

3. SCIENTIFIC INVESTIGATIONS FOR CERTIFICATION

German Air Force started the evaluation and testing process for the new stripping system in early 1985. For PMB the University of the Armed Forces in Munich was invited to conduct a series of investigations. These test series were followed by numerous test series conducted by the aircraft industry (company MBB) and included sheet testing as well as real aircraft testing. Different kinds of sheet materials of aluminium alloys were tested under various stripping conditions during the last 6 years. We learned by experiences, changing the following parameters, PMB is applicable to most of the requirements:

- hardness of pellets,
- distance of the blast nozzle to the sheet,
- angle of the blast nozzle to the horizontal line,
- nozzle diameter,
- pressure.

A summary of the test results is given in figure 5; the test arrangement is shown in figure 6. The first result is, that a remaining bending of the sheet after the stripping action can be measured. (The test sheets were allowed to bend under the blast load.) The reason for this effect is a cold-straining process which is performed by the blast load.

The second result is, that an increase of the surface roughness can be measured. This is due to the abrasive effect of PMB. Up to 50 percent of the upper plated layer of the sheet are removed. "Micro craters" are appearing (fig. 7).

Simultaneously the hardness of the outer zones of the sheet is increased by about 6 to 15 percent. The reason therefore is a cold-hammering process which is performed by every particular hit of a single pellet (fig. 8).

The fatigue resistance was not measured in this test series. It was recommended to execute some fatigue tests and also tests of the adhesive power of a stripped surface. And it is also considered to be of interest to watch the results of a sheet which has been stripped more than one time.

Overall aim of the testing was to obtain the official approval that PMB is suitable for military aircraft. This was finally pronounced by the certifying authority in 1990.

4. PLASTIC MEDIA BLASTING FACILITIES IN GERMANY

Figure 9 explains the existing PMB facilities in Germany and which are planned and who is responsible for them. The first plant built for the entire aircraft was the one at MBB in Manching, Southern Germany, where most of the previous mentioned test series were conducted with aircraft from the 6. US-Fleet and from GAF. Also PA 200s from the German Navy were tested there for corrosion treatment reasons. The results were satisfying. GAF then intended to get more additional experiences. Before building a PMB plant for an entire aircraft at an airforce base, it was decided that GAF should have more detailed experiences to write the specification for it. One additional requirement for this plant was that it should include a

more advanced stripping technology than that at MBB and it should be aware of the most recent environmental protection and health care regulations.

Therefore GAF procured a smaller so called stripping cabin and located it at Erding where GAF's PA 200s get their major maintenance checks. Part of these checks is the stripping of some parts or components of the aircraft for corrosion treatment or modification reasons. This is now done with help of the stripping cabin (figure 12). Because of the good results GAF was able to finish the specification for the greater plant in 1991. It is planned to establish it at the city of Jever near Bremen in Northern Germany, where GAF's F-4s are overhauled, and to be operational in 1994. Funding will commence from 1993 on.

5. EXPERIENCES WITH THE SMALL PLASTIC MEDIA BLASTING CABIN

The small stripping cabin was introduced by the GAF PA 200 maintenance squadron at Erding in 1990. Figure 10 shows how the cabin is installed in an aircraft hangar. With a facility for programming "parameter stripping"-processes our cabin contains a more advanced stripping technology. Heavy contamination of environment and working crew can be avoided.

The technical data of the stripping section of this cabin are as follows:

- length: 8,5 m
- width: 4,0 m
- height: 4,0 m
- main access door: 3,88 x 3,0 m
- crew: 1 worker
- skill level: low
- costs: about 400.000 DM
- additional rubber glove equipment for very small parts

Figure 11 shows a maintenance crew at work. Figure 12 shows a TORNADO wing half before stripping. Our experiences are very satisfying, because the stripping process is not only faster but also much easier to handle than with the traditional chemical system. Even the workers really "like" to do their stripping job. A further advantage of PMB stripping is that extensive cleaning of the parts or components before stripping is not necessary, because remaining dust, oil and grease is purely blasted away while stripping.

This small cabin familiarised a lot of GAF maintenance personnel with this new stripping system and all experiences went into the specifications made for the entire aircraft stripping plant.

6. FUTURE REQUIREMENTS

It has been proven that PMB is suitable for stripping military aircraft. GAF is convinced, that PMB is (at this time) the right system to replace the traditional chemical one. PMB is able to fulfill the environmental and health care requirements as best as possible. Nevertheless technologies are advancing. The next step forward is - as pointed out- to establish an entire aircraft facility in Jever (figure 13). When this plant is operational ready GAF will introduce the stripping process as a scheduled maintenance event for all F-4s. Furthermore the plant in Jever will then execute on request stripping of TRANSALLs and helicopters too. Especially the German Navy has forwarded a constant demand for this possibility. Whether PMB is needed for the entire TORNADO aircraft or for parts only is currently under investigation. A second plant might then be necessary; it's location would be Erding.

Future work will concentrate on the following two efforts:

- Conducting a long term observation program of how the sheet material reacts when blasted three, four or even more times during aircraft life.
- Conducting a specific test program for modern composite materials with the aim of operational readiness of the advanced stripping system when new aircraft come into service.

- | | |
|-----------------------------|--------------------------|
| - DISMANTLING OF CORROSION | - USE OF ABRASIVES |
| - TREATMENT OF CORROSION | - LASER |
| - REPLACEMENT OF PRIMER | - HIGH PRESSURE WATER |
| - PROTECTION OF ENVIRONMENT | - GLASS PEARLS |
| - PROTECTION OF HEALTH | - CARBON DIOXIDE PELLETS |
| | - PLASTIC MEDIA BLASTING |

Figure 1: Requirements

Figure 2: Stripping methods



Figure 3: PMB system and components

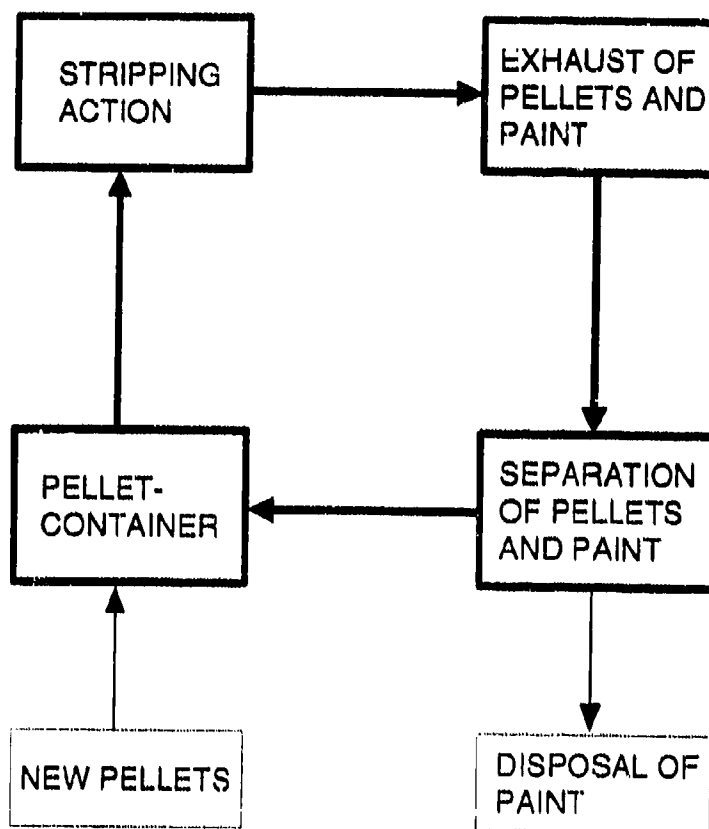


Figure 4: PMB pellet cycle

MEASUREMENTS	RESULTS	REASONS
BENDING	REMAINING BENDING AFTER STRIPPING	COLD - STRAINING
ROUGHNESS	INCREASE	REMOVAL OF UP TO 50% OF PLATED LAYER
HARDNESS	INCREASE	COLD - HAMMERING
FATIGUE	- NOT MEASURED -	

Figure 5: Investigations for certification

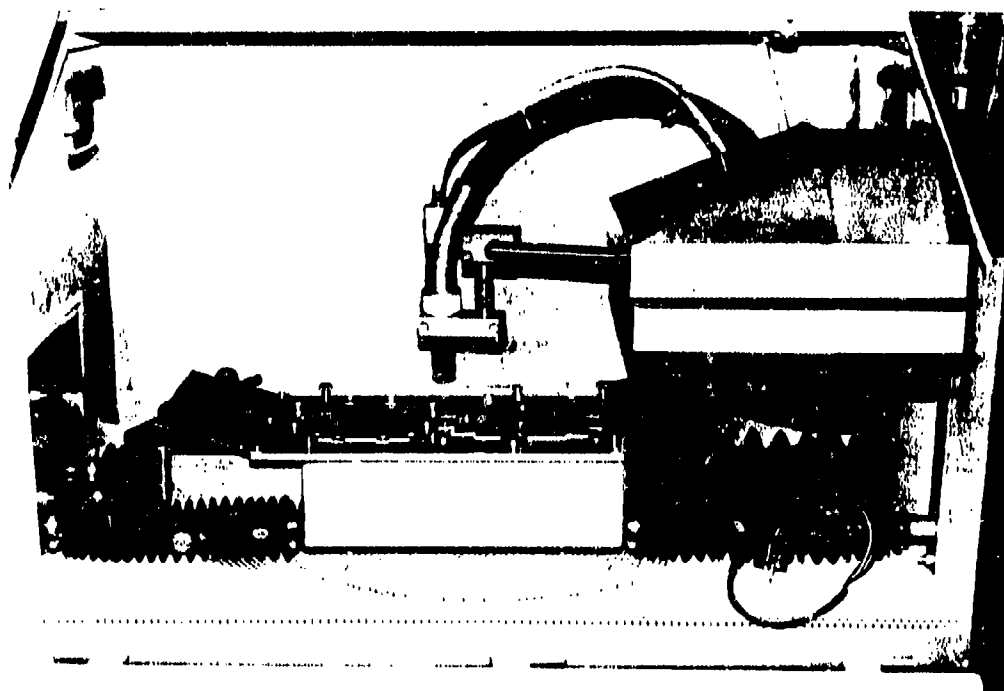


Figure 6: Test arrangement

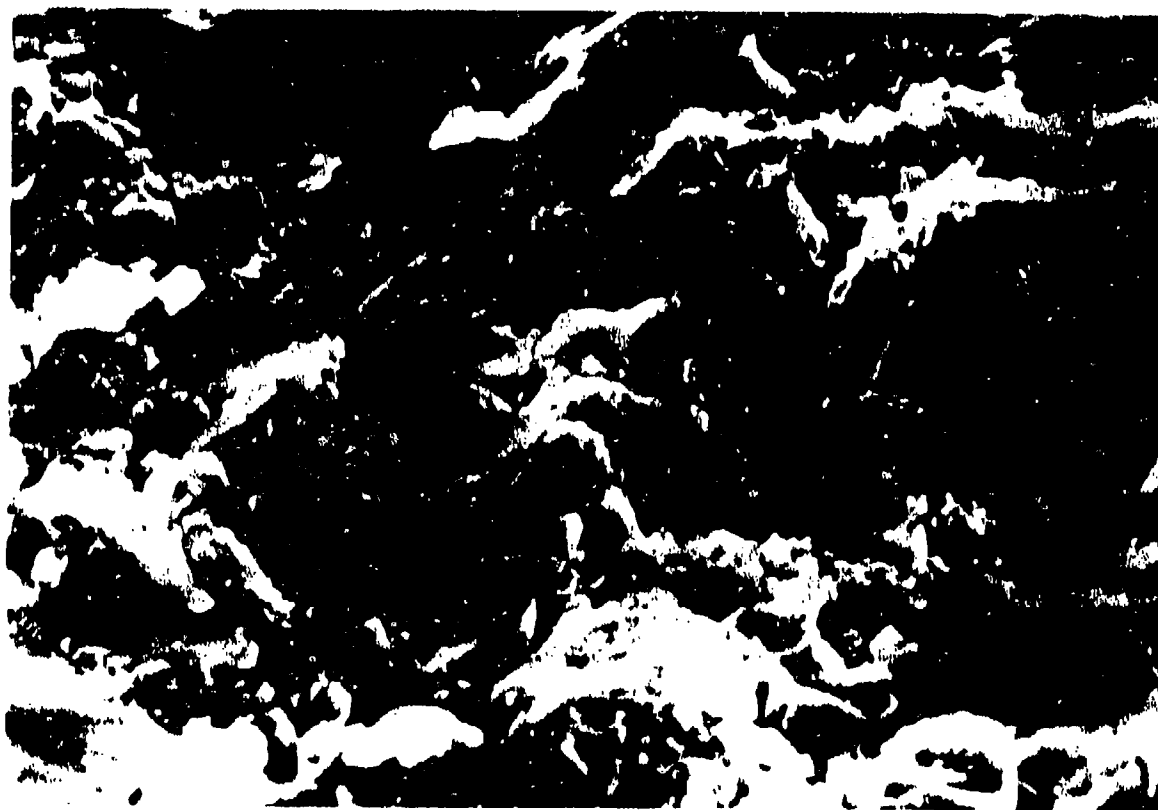


Figure 7: Abrasive effects of PMB

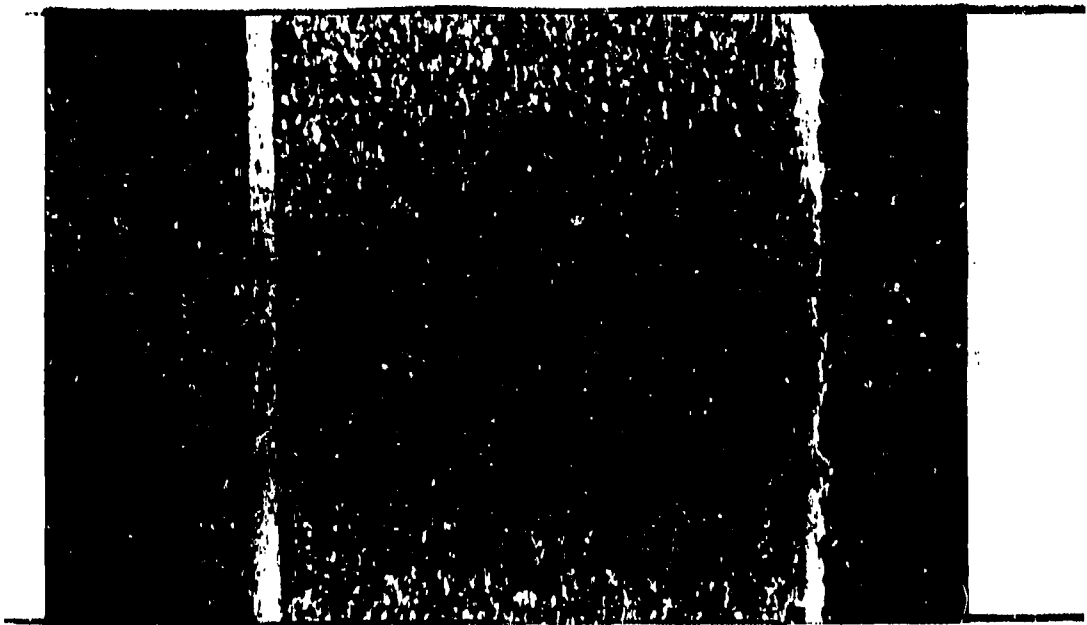
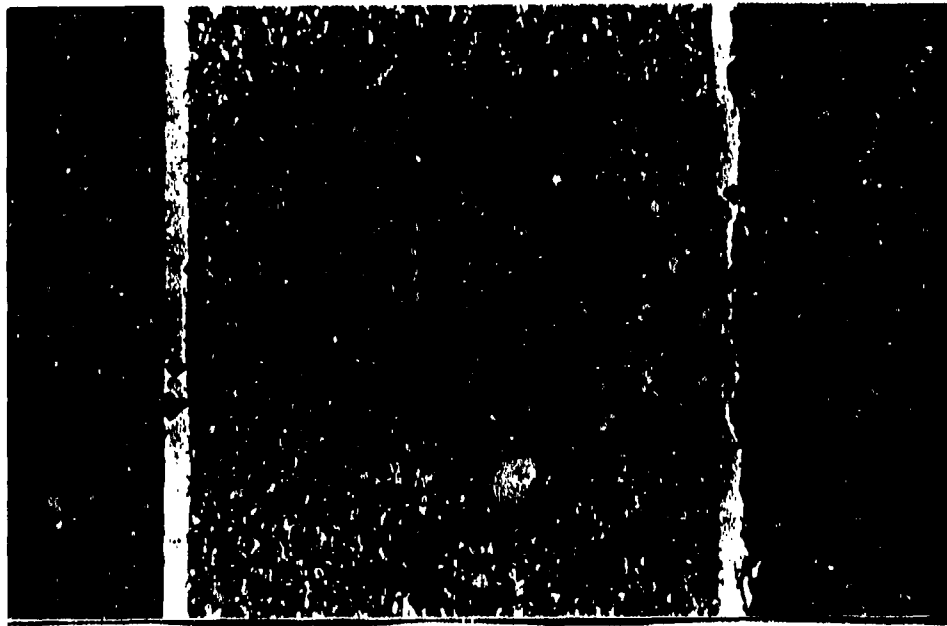


Figure 8: Impacts of hardness probe

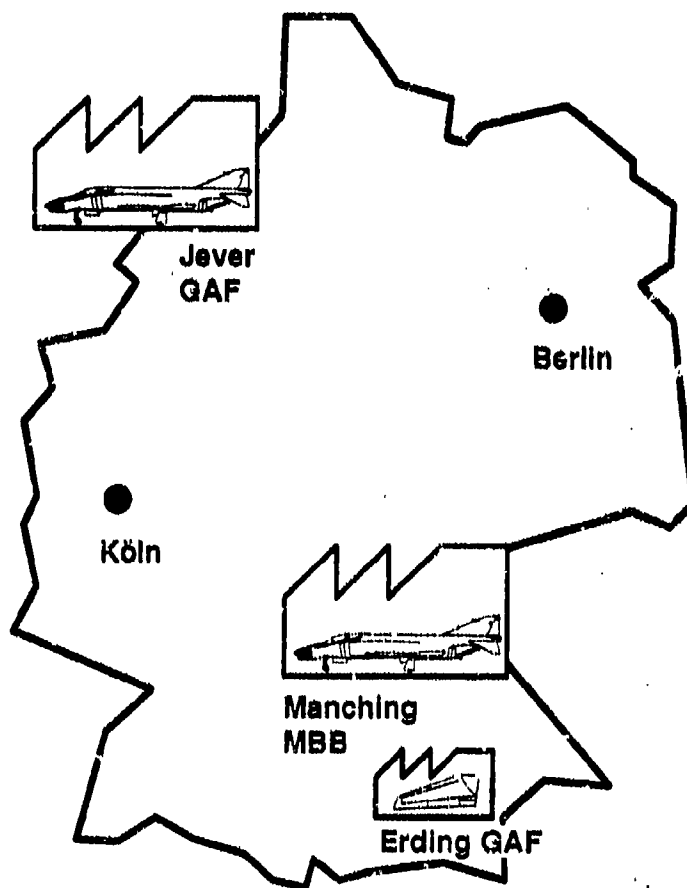


Figure 9: PMB facilities in Germany

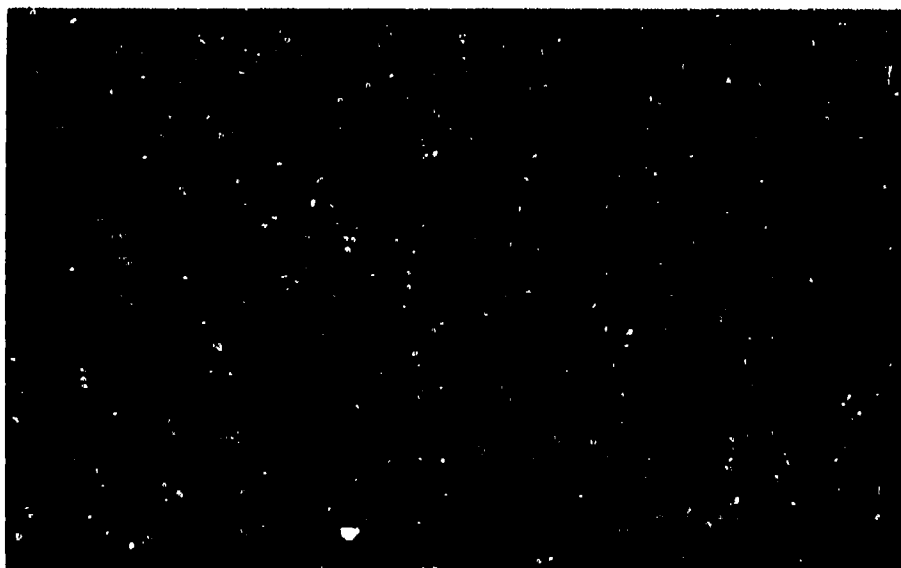


Figure 10: The small PMB cabin

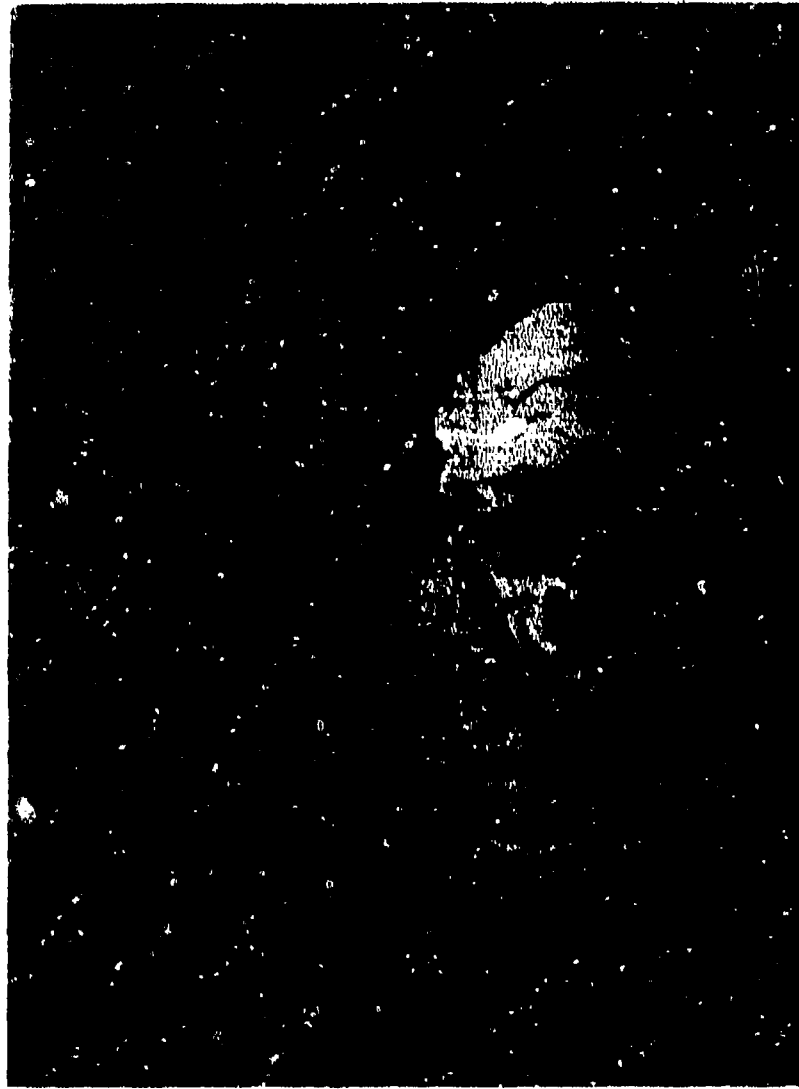


Figure 11: Stripping crew at work



Figure 12: Stripped parts and components

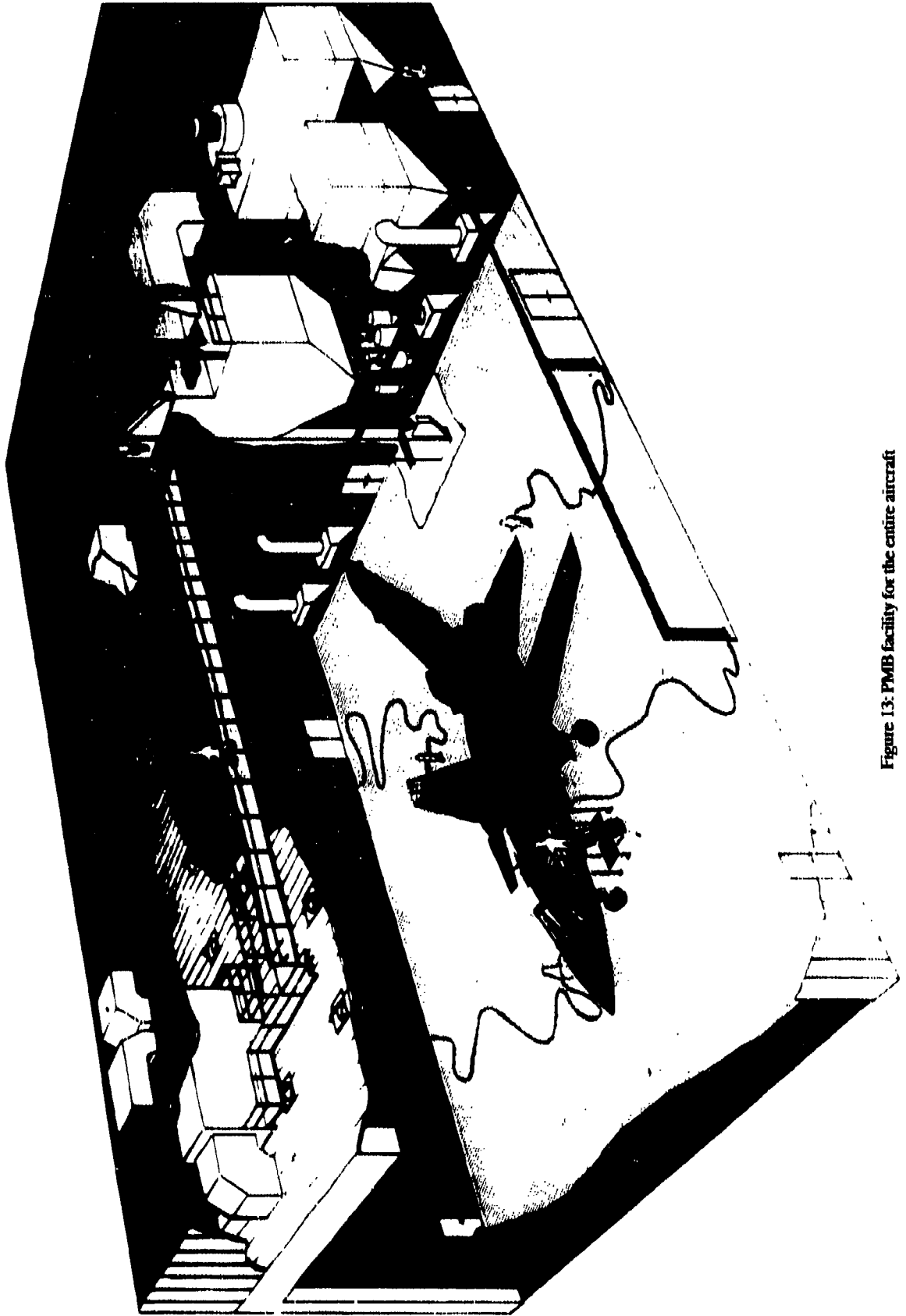


Figure 13: PMB facility for the entire aircraft

PLASTIC MEDIA BLASTING ACTIVITIES AT HILL AIR FORCE BASE

by

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Hill Air Force Base in Utah developed plastic media blasting (PMB) paint removal process for removing paint from Air Force aircraft. The development of the process involved extensive testing of various abrasives and subsequent parameters to end up with an approved production process. Hill AFB has been using PMB in a production mode since 1985, and completely discontinued chemical stripping of airframes in 1989. We have recently installed and began operating a fully automated PMB facility that utilizes two nine-axis robots to strip an aircraft. This system has enabled us to further reduce the manhours required to strip an aircraft, and also allowed us to remove the employee from the blasting atmosphere into a control room. We have, and will continue to realize, significant environmental and economic savings by using PMB. Hill is also actively involved with the development of future paint stripping technologies.

Prior to the eighties, we at Hill AFB were using chemical strippers to remove paint from our aircraft. We knew we had to change from an environmental standpoint; air, water, and solid hazardous wastes. With that, in the 1981-1982 time-frame, we began looking for alternative stripping processes to replace chemical stripping. The thing that looked most promising was a blasting process, but we experimented with many types of abrasives, walnut shells, rice hulls, different plastics, etc. We decided on a thermoset (Type II) plastic media. We developed the proper operating parameters through extensive testing and came up with an approved process and operating procedure to begin production use.

In 1985 we completed construction of the first aircraft plastic media blasting booth. In May 1985, we began production use of PMB and have been successfully using the process ever since. PMB has many benefits. The most significant are the environmental savings. We have totally eliminated the wastewater generated that required treatment at our Industrial Wastewater Treatment Plant, and totally eliminated all air emissions. The hazardous waste is now all in solid form and less in volume, as well as being easier to contain and dispose of.

In addition to the environmental benefits, there are other significant benefits from PMB. The manhours, flowtime, utilities, and material cost are all greatly reduced when using PMB versus chemical stripping.

In 1989, we started production stripping in two additional blast booths. With a total of three booths, we can plastic media blast 100 percent of our workload. We have not chemically stripped an airframe since 1989. The only chemical stripping we do is on the radome and a small number of component parts.

The process our aircraft goes through involves three main steps. First, we prep the aircraft. We use a lot of hot glue, specially made plugs, tape, and putty, and we try to seal the aircraft up so we do not get any plastic inside the aircraft during stripping. Once the aircraft is fully prepped, we go ahead and blast it. We can use up to four blasters at a time. We also have one person recovering the plastic media and another monitoring the process and the equipment. Once we've completed the paint removal, we blow the aircraft off and inspect to see we haven't missed anywhere. Then we begin deprepping. We pull off all the covers, plugs, etc., and we also pull a number of panels to verify we didn't get any ingress. If we did, we remove it at this time.

In order to strip our aircraft without doing damage, there are two key elements. First, you must use clean media, and second, you must have a trained and experienced operator using the correct operating parameters. Those parameters include the correct nozzle pressure (30-40 psi), correct standoff distance (18 inches minimum), correct angle of incidence (45°-90°), correct media for the job, and the proven technique (i.e., no extended dwell time). Our experience is that if you have a trained operator using clean media and the correct parameters, we can blast our aircraft with no damage.

Because we used the first-of-its-kind, full aircraft PMB facility, we have learned some lessons as to what equipment and facility options work best for us. The first thing we learned was that you need to have an independent ventilation system and floor recovery system. The ventilation system should be designed for end-to-end laminar airflow. The volume of air required is dependent upon the size of the blast facility. We've tried both mechanical and pneumatic floor recovery systems, both full floor and partial floor recovery. What has, and will work the best for us, is a partial floor pneumatic recovery system. A properly designed pneumatic floor seems to work the best from a production and maintenance standpoint.

We have experience with both single stage and double stage pressure pots. The single stage pot seems to work best for our manual blasting. The robots require a double stage in order to operate, but for manual stripping, we've determined a simple single stage pot to be the most productive for our operation.

As I mentioned previously, we must use clean media in order to avoid damage. We have a four stage classification system that accomplished the cleaning of our media before reuse. The first stage is a cyclone separator that pulls out some of the dust and fine particles. The second stage is a classifier. This has two screens: an oversized screen for large paint chips, and an undersized screen for the dust. The third stage is a magnetic separator that separates out any ferrous material and the

fourth stage is a dense particle separator. This is required to separate out a particle the same size as the useable plastic, but heavier, i.e., sand, brass, glass, etc.

Hill AFB has just completed a three-phase repair technology (Reptech) project to automate paint stripping of fighter size aircraft. The first phase of this project was to identify what paint stripping process was the most feasible to automate, and based on that decision, do a preliminary design of the work-cell. The second phase was to complete a detailed design and actually fabricate the two robots, and test them at the contractor's site. Phase three was to deliver the equipment, install, program, and start-up operation. The system includes two nine-axis robots that are computer controlled. Each robot is preprogrammed for the stripping paths on the aircraft, as well as the operating parameters preprogrammed for each specific stripping path. The only variable requiring feedback control is the velocity of the end effector. Every aircraft has different paint adhesion, as well as different paint thickness. To allow for these variables, our robots have paint sensors

which, in a real-time basis, adjust the speed of the end effector such that we do not overblast, but at the same time, we do not leave any paint behind. This equipment is installed and is being used in a production environment.

Hill AFB is also very involved, and actively participating in, the development of future paint stripping technologies. We currently have a project to develop and install an automated CO₂ laser radome paint stripping cell. As previously mentioned, the only area we still chemically strip is the radome. For this reason, we are actively pursuing replacing that with an automated laser system.

We have also done some work with wheat starch or enviro-strip abrasive. This process did work and is feasible for our radomes, and we plan to use this as an interim solution until our automated system is installed.

We are also following the industry developments with high-pressure water stripping and CO₂ blasting.

Large Aircraft Robotic Paint Stripping (LARPS) System and the High Pressure Water Process

USAF Contract No. F33615-91-C-5708

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ABSTRACT

The aircraft maintenance industry is beset by new Environmental Protection Agency (EPA) guidelines on air emissions, Occupational Safety and Health Administration (OSHA) standards, dwindling labor markets, Federal Aviation Administration (FAA) safety guidelines, and increased operating costs. In light of these factors, the USAF's Wright Laboratory Manufacturing Technology Directorate and the Aircraft Division of the Oklahoma City Air Logistics Center initiated a MANTECH/REPTECH effort to automate an alternate paint removal method and eliminate the current manual methylene chloride chemical stripping methods.

This paper presents some of the background and history of the LARPS program, describes the LARPS system, documents the projected operational flow, quantifies some of the projected system benefits and describes the High Pressure Water Stripping Process.

Certification of an alternative paint removal method to replace the current chemical process is

being performed in two phases: Process Optimization and Process Validation. This paper also presents the results of the Process Optimization for metal substrates. Data on the coating removal rate, residual stresses, surface roughness, preliminary process envelopes, and technical plans for process Validation Testing will be discussed.

INTRODUCTION AND BACKGROUND

Although methylene chloride based chemical strippers are the most widely used in the aircraft industry (including military depot maintenance activities), the strippers will soon be a thing of the past. At the Oklahoma City Air Logistics Center, environmental programs dictate that methylene chloride use be halved by 1995 and eliminated by the year 2000. In conjunction with the Wright Laboratory Manufacturing Technology Directorate (Wright-Patterson Air Force Base, Ohio, USA) a MANTECH/REPTECH program was developed to demonstrate the automation of an alternative method of removing paint to aid in meeting these environmental goals.

The USAF request for interested parties to develop a "Large Aircraft Robotic Paint Stripping" (LARPS) system was announced in December, 1989. A RFP was released in October, 1990 and proposals were received in February, 1991. Contract no. F33615-91-C-5708 (LARPS) was awarded to United Technologies, USBI Co. in July, 1991.

Program requirements include:

- Reducing hazardous waste by 90%
- Achieving an availability of 85% while seeking to achieve 95%
- and Maintaining aircraft surface quality

Program goals include:

- Reducing organic coating removal flow time by 50% over present flow times
- Reducing labor hours by 50%

Program characteristics include:

- Reduced labor hours
- Reduced cycle time
- Reduced exposure to hazardous environments
- Reduced cost
- Reduced hazardous waste production

OC-ALC currently performs paint removal operations as part of their programmed depot maintenance (PDM) activities on the following aircraft.

- Boeing B-52
- Boeing C-135 series
- Boeing E-3
- Rockwell B-1B

CURRENT OPERATIONS

The hangar targeted for LARPS is the south hangar, west bay (Bay I) of Tinker AFB's Building 3105, shown in Figure 1, is approximately 35 feet (10.7 meters) tall, 150 feet (45.7 meters) wide and 225 feet (68.6 meters) long.

Aircraft Strip Configurations

Each aircraft type has a different configuration for stripping. Within each of the four aircraft types, variations may also occur from plane-to-plane in what components are on, or off, the aircraft. The wingspan of the B-52 prohibits the aircraft from being brought into the Building 3105. The E-3 is prohibited from entering the hangar due to the height of the rotodome. There are over 50 different components which are removed from the B-52 and stripped separately from the aircraft.

The C-135 is backed or pulled into the hangar (Figure 2). The tail of the C-135 is taller than the ceiling height of the hangar. Therefore, it is re-

moved and processed on a separate mounting fixture; horizontal stabilizers are also removed. Engine status (removed or not removed) varies on the C-135 depending on the engine type. There are over 100 different components which are removed from the C-135 and stripped separately from the aircraft.

The B-1B will be positioned at an angle to allow the robot to pass the wing tips. The B-1B wingspan would not allow the required clearance in the straight-in position. No structural components are removed from the aircraft for stripping. Wings are kept in the extended position during the entire operation.

Current Paint Removal Operations

Aircraft are currently stripped in OC-ALC Building 2122, Bay I and II. Each aircraft has its own set of process steps. These steps are documented on "work cards", computer printed instructions that list the operation to be performed and the standard hours to perform it. At a summary level the operations can be grouped into masking, stripping and closeout.

Preparation and Masking. The aircraft is first towed into the facility. Static ground cables and ground safety locks and pins are installed. After the aircraft is positioned in the bay, areas to be chemically stripped are cleaned of grease, oil or dirt to assure maximum efficiency of the stripping compound.

Openings that would permit stripper to get into aircraft interiors or critical cavities are masked. Masking is customized for each aircraft. Most areas are masked with a custom cut piece of aluminized plastic and tape, or tape only. Generally, areas masked include:

- Landing gear and wheel wells
- Wing cavities (where control surfaces have been removed)
- Engine mounts, inlets and exhausts (depending on whether the engines are on or off the aircraft)
- Radomes
- Antennas
- Pitot tubes
- Static ports
- Miscellaneous openings (where components have been removed)
- Windows
- Drain holes
- APU exhaust doors
- Safety discharge discs and discharge indicators
- Composite substrates and fiberglass repairs of flaps

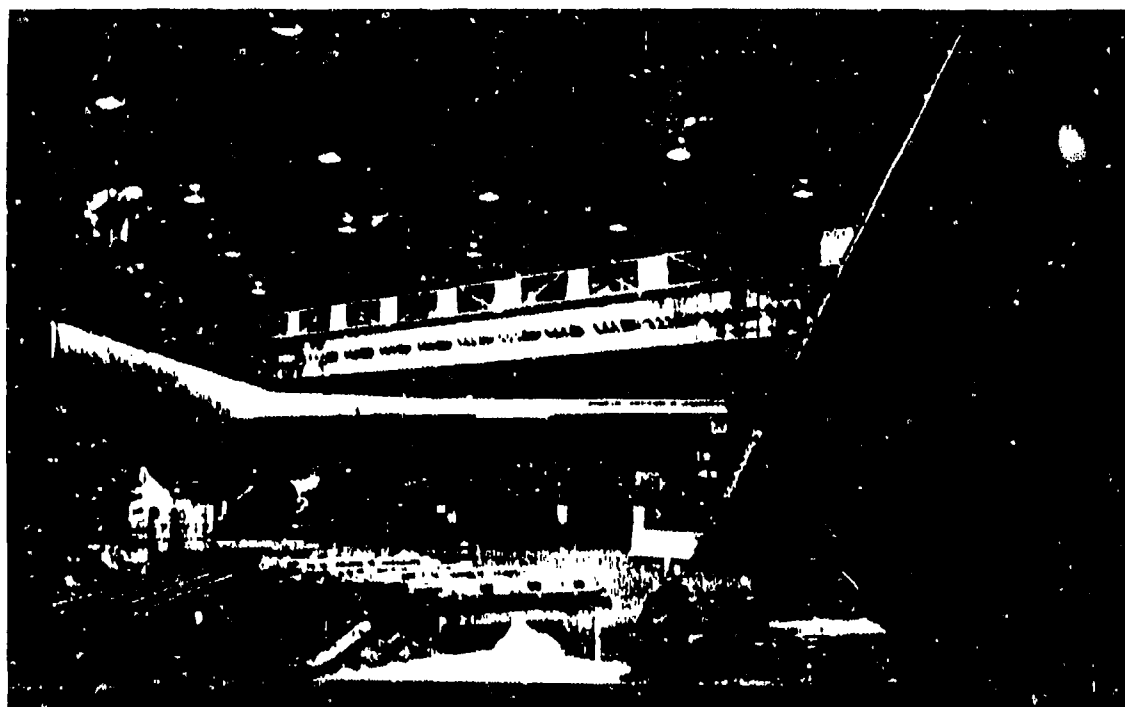


Figure 1 - Bay 1

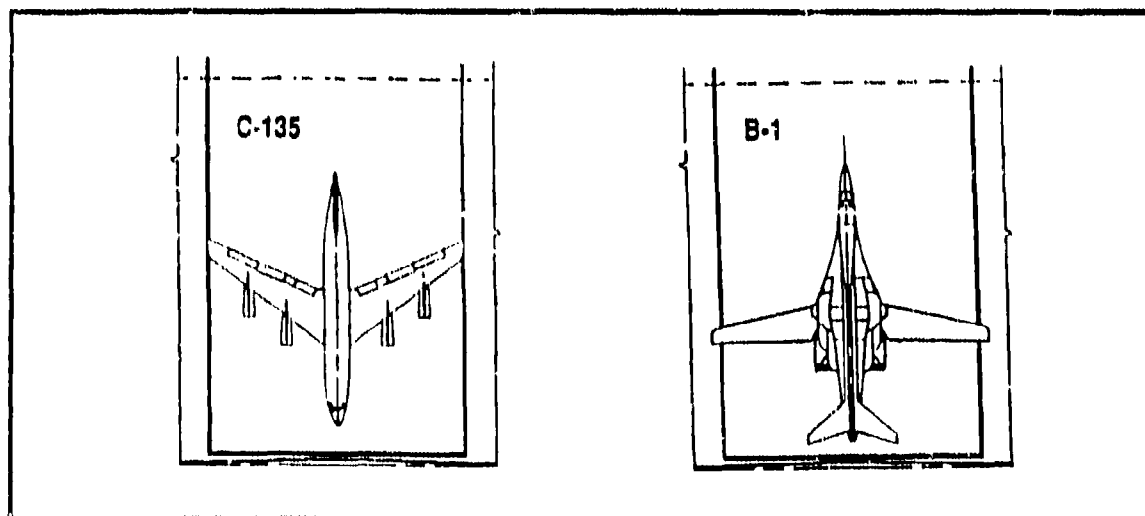


Figure 2 - Aircraft Positioning In Bay 1

Stripping

The methylene chloride stripper is applied to areas of the aircraft, or the entire aircraft and allowed to set, penetrating the paint for approximately 1-5 hours. The paint film can then be washed off with low pressure water at 50-100 psi. Putty knives, scrapers and brushes are also used when needed to thoroughly remove the paint. In some areas the stripper is reapplied and rinsed a second or third time.

Chemicals are sprayed with a wand in a fan pattern, and are pumped pneumatically directly out of barrels. The barrels are placed in the work area near the corner of the facility. In addition to falling on the floor, chemicals drip onto barrels and workstands and must be continuously rinsed off. The floor is sprayed with water before the chemicals are applied to the aircraft and rinsed several times during the stripping process.

Workers use air respirators and protective clothing when spraying chemicals. Squeegees are used to remove loosened paint. The process is repeated up to 3 times depending on the paint system. For polyurethane topcoat and epoxy primer paint systems this includes two times with a phenolic stripper to remove the topcoat and one time with a polysulfide stripper to remove the primer. After stripping, the aircraft is scrubbed with alkaline soap and water and then rinsed.

Movable workstands are used to allow the workers to reach the height of the B-52 and C-135 vertical stabilizers. Line generated parts and MISTR (maintenance items subject to repair) are either chemically stripped in Bays I or III, or plastic media blasted in Bay II (of Building 2122).

Cleanup/Touchup/Closeout

After stripping, the masking is removed from the aircraft and touchup activities are performed. Remaining primer or paint are often scuff sanded to insure the complete removal of the topcoat and primer from the aircraft.

Current Costs

Costs are based on stripping an average annual workload of three B-52s, sixty-two C-135s, one B-1B and nine E-3s. Direct, unburdened labor expenditures are approximately \$1.34M annually.

Consumable materials used during chemical stripping operations; such as, plastic, aluminum tape, barrier material, alodine, stripper, soap and solvent, require expenditures of approximately \$1.23M annually. Hazardous waste is grouped into three categories: solid hazardous waste, industrial rinse water and air emissions. Current amounts of hazardous wastes are discussed in the following sections. The first component of the solid hazardous waste is sludge pulled from trench screens in Building 2122 (1500-3000 lbs per plane) and the second is a finer sludge pulled from settling basins (100,000 lbs per year). Neither of these make it to the waste treatment plant. The solid hazardous waste expenditures for Bay I are approximately \$0.37M annually.

The treatment facility handles waste from all of Tinker AFB. Accumulated solid hazardous waste from Building 2122 cannot be distinguished from other waste. Treatable water waste is the effluent sent from Building 2122 to the treatment plant. Waste treatment expenditures are approximately \$0.03M annually for the quantity of water sent from paint removal operations. Two-hundred seventy tons of VOCs are emitted annually in Building 2122. The VOC emissions are directly proportional to the amount of chemical stripper used on the aircraft. All direct costs associated with current chemical stripping operations presented in the previous sections are approximately \$3.0M annually.

Current Cycle Times

Current cycle times are shown in Table 1. Note that the sum of the total days for all aircraft except the E-3 are applicable to Bays I and III of Building 2122. Bay I is the primary dock. E-3 flow days impact the paint hangar, Building 2280.

Table 1 - Current Cycle Times

Aircraft	Flow Days	Worked	Total Days
B-52G	5	3	15
C-135	5	62	310
E-3	5	9	45
B-1B	6	1	6
Total			376
Total (w/o E-3)			331

SYSTEM DESCRIPTION

The current LARPS system configuration is shown in Figure 3. The system consists of a robot subsystem, a computer subsystem, a sensor

provide complete coverage. Utilities and communication lines are fed to the robot through an overhead boom, which travels along a suspended

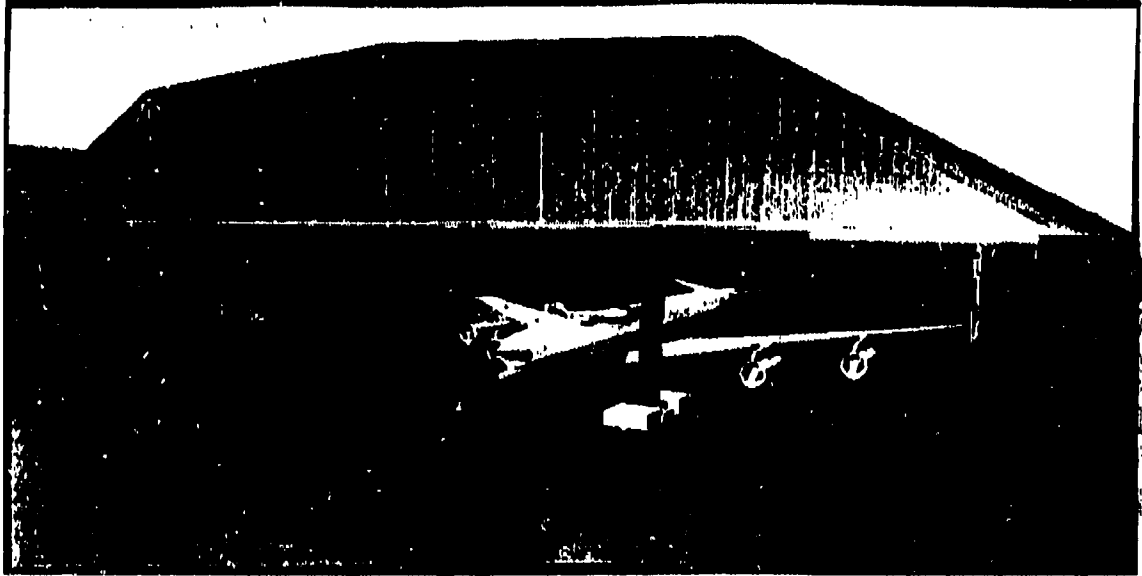


Figure 3 - LARPS System

subsystem, a guidance subsystem, a paint removal subsystem and a facility subsystem.

monorail. Selected specifications for the robot subsystem are shown in Table 2.

The robot subsystem (Figure 4) consists of a pedestal manipulator mounted to a SCARA (originally termed as a "selective compliant assembly robot arm"). The SCARA moves vertically on rails mounted to the column. The column rotates on a turntable mounted on the deck of the transporter. The transporter moves the robot subsystem from location to location following guidewires. Each aircraft requires multiple stop points around it to

The computer subsystem includes the host computer, operator's station, access terminals and peripheral devices. The LARPS system operator will interface primarily through the operator's terminal. Most of the computer equipment will be located in operator's control room and adjacent computer room. A computer model of the operator's control room is shown in Figure 5.

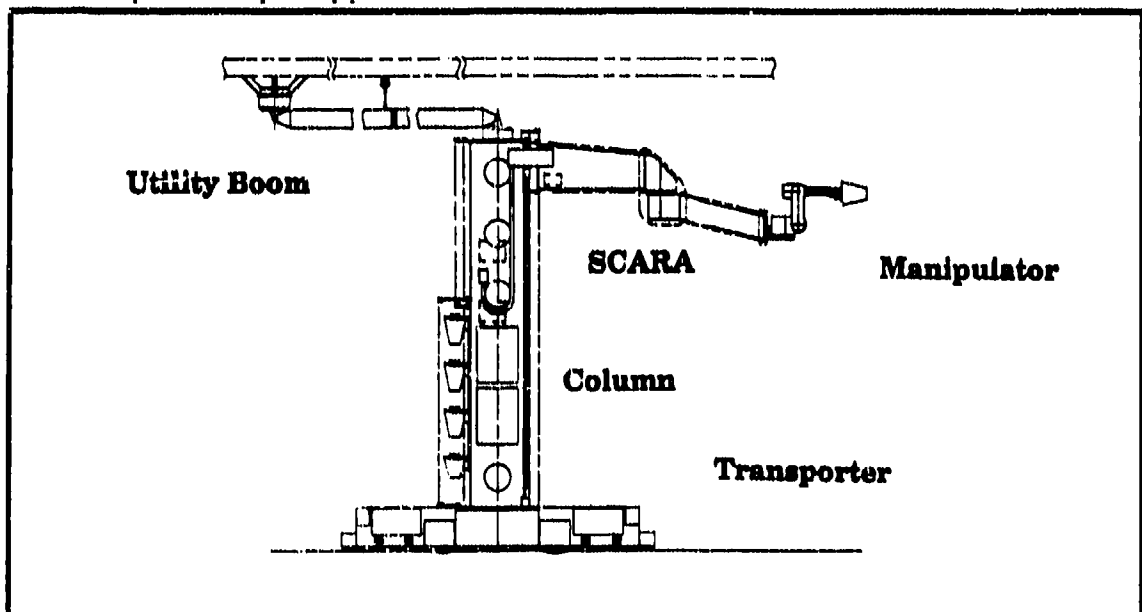


Figure 4 - Robot Subsystem

Table 2 - Selected Robot Subsystem Specifications

Column Height	30 feet (9.2 meters)
Transporter Width	10 feet (3.0 meters)
Transporter Length	23 1/2 feet (7.2 meters)
Total Weight	50,000 lbs (22,700 kg)
Horizontal Reach*	28 feet (8.5 meters)
Vertical Reach*	0 to 29 feet (8.8 meters)
Payload	125 lbs (56.8 kg)
Maximum TCP Velocity	24 inches/second (0.6 meters)
Repeatability	±0.25 inches (±6 mm), 3-σ 1/2 inches (50 mm)/second
Degrees of Freedom	9 servo controlled

• *measured at the faceplate*

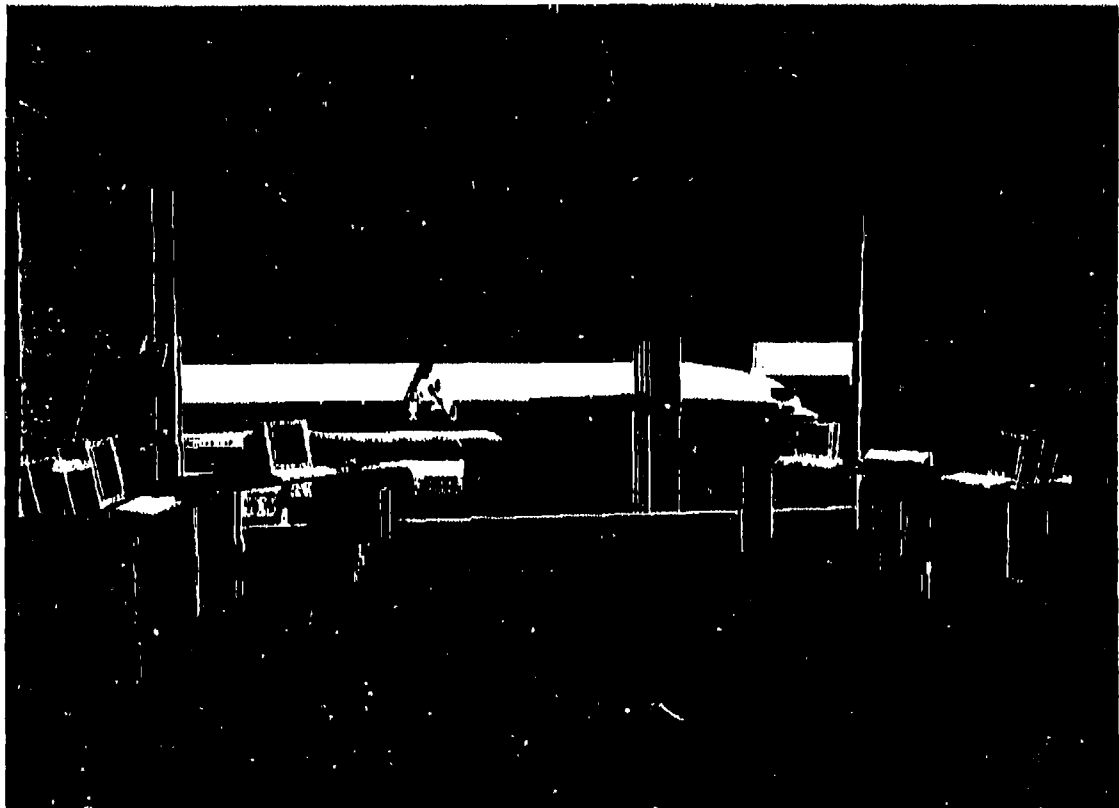


Figure 5 - Operator Control Room

The majority of sensor subsystem components are located on the robot subsystem or various process end-effectors. These include standoff control, collision avoidance and paint removal quality sensors on the end-effectors, and collision avoidance sensors on the transporter, column, SCARA and manipulator. Sensor data is collected and processed by the sensor controller.

The guidance subsystem is comprised of three parts: (1) global location, (2) surface mapping and (3) path generation. The global location function serves to locate the position of the aircraft in the hangar, and correlate the actual position of the aircraft to the position modelled in the computer database. The surface mapping function provides an accurate contour map of the aircraft surface which is used to further update the computer database. From this database, the actual robot path programs are generated.

The paint removal subsystem consists of the high pressure pump, end-effectors and water supply lines (along with miscellaneous valves, couplings and transducers). High pressure water is supplied to the end-effector from the remotely located high pressure pump. The facility subsystem includes the water recovery and reclamation system which provides supply water to the

pump. Water is recirculated locally to Bay I during processing operations.

PROJECTED OPERATIONS

The LARPS system will be capable of accommodating each of the candidate aircraft. However, since the E-3 and B-52 do not fit in the hangar designated, they will not be processed with the LARPS system initially. The E-3 and B-52 will continue to be stripped in the same manner as currently performed until such time that a new, larger facility for the LARPS system can be activated.

The aircraft strip configuration will be left intact as far as the components to be removed are concerned. A significant reduction in the number of masking hours is anticipated, however.

The LARPS projected operational flow is shown in Figure 6. Preparation and masking activities will be performed, followed by system start-up and transporter movement to the first stop location. After reaching the first stop location, global location and surface mapping will occur. After completing mapping and paint removal at every stop location the transporter will be returned to its home position and the system will be shutdown.

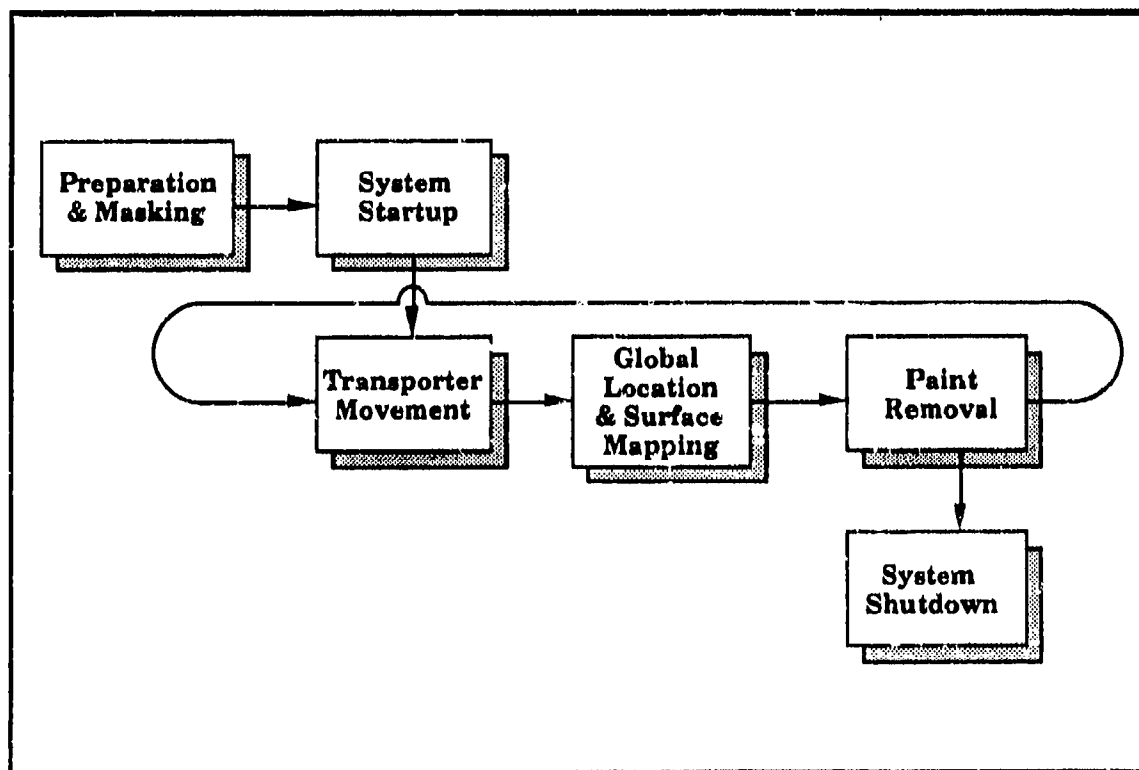


Figure 6 - LARPS Operational Flow

During preparation and masking, the aircraft will be parked in its required location within the workcell. The optimal location for the landing gear will be marked on the floor with rectangles representing the tire footprint.

After positioning the aircraft, limited masking will be performed for LARPS paint removal operations. A detailed review of the work control documents for each masking step was undertaken as part of the LARPS requirements definition and needs analysis task. For the C-135, it appears that only five masking operations will be required (15 hours). For the B-1B, it appears that approximately ten masking steps will be required for a total of 48-54 standard hours. These represent a 75-95% reduction in masking standard hours. Supports will be located at the wing tips to provide wing stability during processing.

The operator will be required to input information during system start-up such as the aircraft tail number, aircraft type, paint type and stripping configuration. The bay will be clear of all personnel before the transporter moves to its first stop location.

During operations, the robot will move from stopping position to stopping position around the aircraft performing the surface mapping and paint removal operations each time. Aircraft will typically have 14-16 robot locations around them

for complete processing. As an example, typical stop positions for a C-135 are shown in Figure 7. The transporter will then level itself on leveling pads in the floor and then obtain the surface mapping end-effector. Depending on the complexity of the surface, fewer (or more), contour data points will be collected. The purpose of globally locating and mapping the surface of the aircraft is to:

- Account for variation in wing location and aircraft positioning
- Determine surface features that are not in the initial robot path programs
- Provide offsets to adjust robot path programs
- Accommodate overall variations between aircraft within a series

After mapping, the end-effector will be placed back in the storage rack and the appropriate paint removal end-effector obtained. Following the updated robot path program, the end-effector will move across the surface of the aircraft, removing paint as it travels. During this time, the paint removal quality sensor will be actively monitoring the stripping process.

During demasking and closeout, masking material previously applied will be removed. Any touchup operations requiring chemical strippers will be conducted in Bay III.

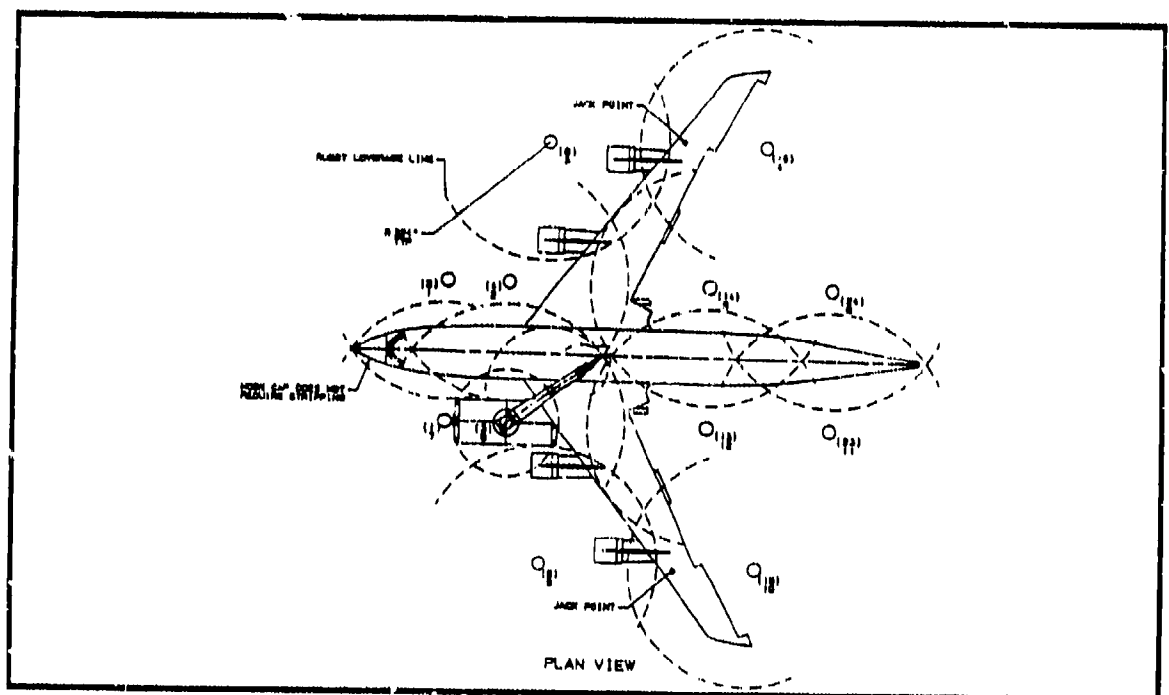


Figure 7 - C-135 Typical Stop Positions

Cycle Times

The projected number of shifts for the LARPS system to remove paint from the candidate aircraft is shown in Table 3. The shifts required to strip an aircraft are calculated by dividing the total surface

area by the strip rate using a 60 minute hour and a 7 hour utilization shift. The surface areas of line generated parts (off the aircraft) are estimated in the column entitled "Surface Area Removed."

Table 3 - Required Shifts

	Surface Area of Aircraft (ft ²)	Surface Area Removed (ft ²)	Total Surface Area (ft ²)	Mask Time (Shifts)	Strip Time* (Shifts)	Demask Time (Shifts)	Flow Days**
C-135	10,000	1,000	9,000	1	12	1	5
B-1B	10,000	0	10,000	1	15	1	6

* Paint removal rate of 1.77 square feet per hour
Mapping time of 1 hour per stop position
Include preventive maintenance time

** Assumes three shift operation

Projected Costs

Labor projections for the same annual average workload used to calculate current costs is \$0.77M. Material usage projections are \$0.59M. Waste disposal costs are projected at \$0.07M. Water treatment costs are projected at \$0.01M. The direct operating and expense estimate for the LARPS system is \$1.4M annually.

A 52% reduction in overall costs is projected for the LARPS system over current operations. If the E-3 and B-52 could be processed in the hanger, the reduction in overall costs would increase to 60%.

Additional cost benefits will be realized in the areas of safety, health and cost of lost production (due to the loss of methylene chloride as a stripper without an alternative with a comparable stripping time). These savings are projected as \$3-4M annually as shown in Table 4.

BENEFITS ANALYSIS

Cost Benefits

A 43% reduction in labor costs is projected for the LARPS system over current operations. If the E-3 and B-52 could be processed in the hanger, the reduction in labor costs would be approximately the same as the C-135, 43%, on a per aircraft basis. The overall reduction in labor costs for OC/ALC would increase to 49%.

A 55% reduction in material costs is projected for the LARPS system over current operations. Processing the E-3 and B-52 would increase this reduction to 63%. A 90% reduction in waste quantities and costs is projected for the LARPS system.

Throughput

Current and projected cycle times are compared in Table 5.

Two-Robot Scenario

Clearly, the addition of a second robot and related equipment would have additional benefits for OC-ALC. By doubling the current high pressure water paint removal rate of 1.77 square feet per minute to 3.54 square feet per minute, the shifts for paint removal would contribute to required flow days of three (9 shifts) for the C-135 and three (9 shifts) for the B-1B.

Table 4 - Cost Benefits

	CURRENT ANNUAL COSTS (note 1)	LARPS PROJECTED ANNUAL COSTS	ANNUAL SAVINGS
OPERATING EXPENSES			
Labor	\$1,342,000	\$680,000	
Material	\$1,230,000	\$326,000	
Disposal	\$335,000	\$34,000	
Treatment	\$30,000	\$3,000	
SUB-TOTAL	\$1,937,000	\$1,043,000	\$1,894,000
HEALTH AND SAFETY (note 2)			
Cost of Lost Days (Injury)	\$7,000	\$0	
Cost of Lost Days (Sickness)	\$87,000	\$15,000	
Cost of Replacement Labor	\$94,000	\$15,000	
SUB-TOTAL	\$188,000	\$30,000	\$158,000
ENVIRONMENTAL			
Potential Fines (note 3)	\$440,000	\$0	
Cost of Lost Production (note 4)	\$1,500,000	\$0	
SUB-TOTAL	\$1,940,000	\$0	\$1,500,000
TOTAL SAVINGS PER YEAR (all costs)			\$3,352,000

(1) Based on FY 1991 OC/ALC workload (3 B-52a, 62 C-135a, 9 E-3a, 1 B-1B); all costs in 91\$
 (2) Projections as of 3/18/92 based on absentee rates
 (3) Estimated fines for not meeting EPA and OSHA guidelines by FY1995
 (4) Current alternative to methylene chloride stripper is another chemical stripper which increases flow time by 50%. This means that the current workload revenues of \$3M would be cut in half.

Table 5 - Throughput Comparison

	Workload	Current Flow Days	Current Total Days	Projected Flow Days	Projected Total Days
B-52	3	5	15	5	15
C-135	62	5	310	5	310
E-3	9	5	45	5	45
B-1B	1	6	6	6	6
Total			376		376
Total (w/o E-3)			331		331

A projected total flow days of 201 as opposed to 337 would be realized based on three shift operations. These calculations are shown in Table 6. This benefit could also be used to continue to meet current timelines but return to two shifts from three shifts.

A labor savings of 13% is projected for a two-robot system over a one-robot system. Likewise, for a two-robot system, a labor savings of 50% is projected over current operations. The E-3 and B-52 are not included in these calculations but would further reduce the labor costs if able to be stripped by a two-robot LARPS system in Building 3105. Material, waste disposal and waste treatment costs remain essentially the same for a two-robot scenario.

In summary, the major benefit of the two robot case is a decrease in annual flow days (based on annual average workload) of 130 days. This equates to a reduction of 39% over current operations. This reduction could also be translated into scheduled two shift operations, leaving third shift open for growth.

Benefits to other USAF ALCs and the DoD

If an overall cost reduction of 52% can be realized at OC-ALC, then other USAF ALCs (Ogden, Sacramento, San Antonio and Warner Robins) could expect similar results. For example, at SA-ALC, paint removal operations for a C-5 cargo aircraft require 5096 man-hours. Applying the reduction projected for a single system, a reduction of over

2000 man-hours could be expected. Most of this would come from masking, where over 2200 hours are expended.

The LARPS system has the vertical reach capability to process the highest point of the C-5's fuselage and the horizontal reach to process the majority of the aircraft surface area. The C-5, the KC-10 and the E-4 are the only aircraft in the DoD inventory which have surface areas outside the current LARPS system. The limited areas not reachable are mainly the tails of these three aircraft where a higher vertical reach is necessary.

THE HIGH PRESSURE WATER PROCESS

USBI is developing high pressure water as the alternative paint removal method for the LARPS system.

An extensive materials evaluation is being performed by USBI to certify the high pressure water process for the LARPS program. This certification is being performed in three segments: Process Optimization, Process Validation Testing, and Additional Materials Testing. These segments will investigate the process effects on metallic and composite substrates to verify that the post-process properties remain within acceptable performance limits and that coating removal rates meet or exceed the current aircraft refurbishment times. The Process Optimization and Validation Testing roadmap is shown in Figure 7.

Table 6 - Comparison of One-Robot and Two-Robot Scenarios

Aircraft	Workload	One Robot Flow Days	One Robot Total Days	Two Robot Flow Days	Two Robot Total Days
B-52G	3	7	21	4	12
C-135	62	5	310	3	186
E-3	9	5	45	5	45
B-1B	1	6	6	3	6
Total			382		246
Total (w/o E-3)			337		201

Process Optimization is divided into two parts: metals evaluation and composites evaluation. The objective of this segment is to generate and assimilate the preliminary parametric data for removing Air Force coatings. During metals evaluation, USBI is investigating coating removal rate, stripping rate efficiency, residual stress, and substrate response. The results will be used to define the preliminary processing envelopes for the next test segment, Process Validation Testing. The composites testing will be performed after award of the next phase in FY 1993.

Process Validation Testing has been divided into three parts: metals evaluation, composites evaluation, and butt/lap/fastener panel evaluation. During Process Validation Testing, USBI will investigate the process effects of high pressure water on the mechanical properties of metallic and composite substrates. The test results will be used to assess the mechanical properties of the substrates after high pressure water processing and to establish the final process envelopes for large scale, robotic paint stripping.

Last, the capabilities of the high pressure water

process to remove coating systems from numerous metallic substrates will be evaluated during the Additional Materials Testing. This test segment will investigate the coating removal rate. The data generated during these three segments will be used by the Air Force to certify the high pressure water process for use of the LARPS system on the candidate aircraft.

This paper presents the test results that have been generated during the Process Optimization testing of metallic substrates. Material descriptions, preparation procedures, test methods, and test results will be discussed. Typical preliminary process envelopes and Process Validation Testing plans will be presented.

The high pressure waterjet process currently being developed by USBI employs high pressure, low volumetric flow rates to remove the coating systems being used by the Air Force. Typically, waterjet pressures of 24,000 psi and volumetric flow rates of less than 5 gallons per minute are used. The waterjet flow is controlled using nozzles specially designed by USBI to provide a uniformly distributed waterjet stripping intensity as shown

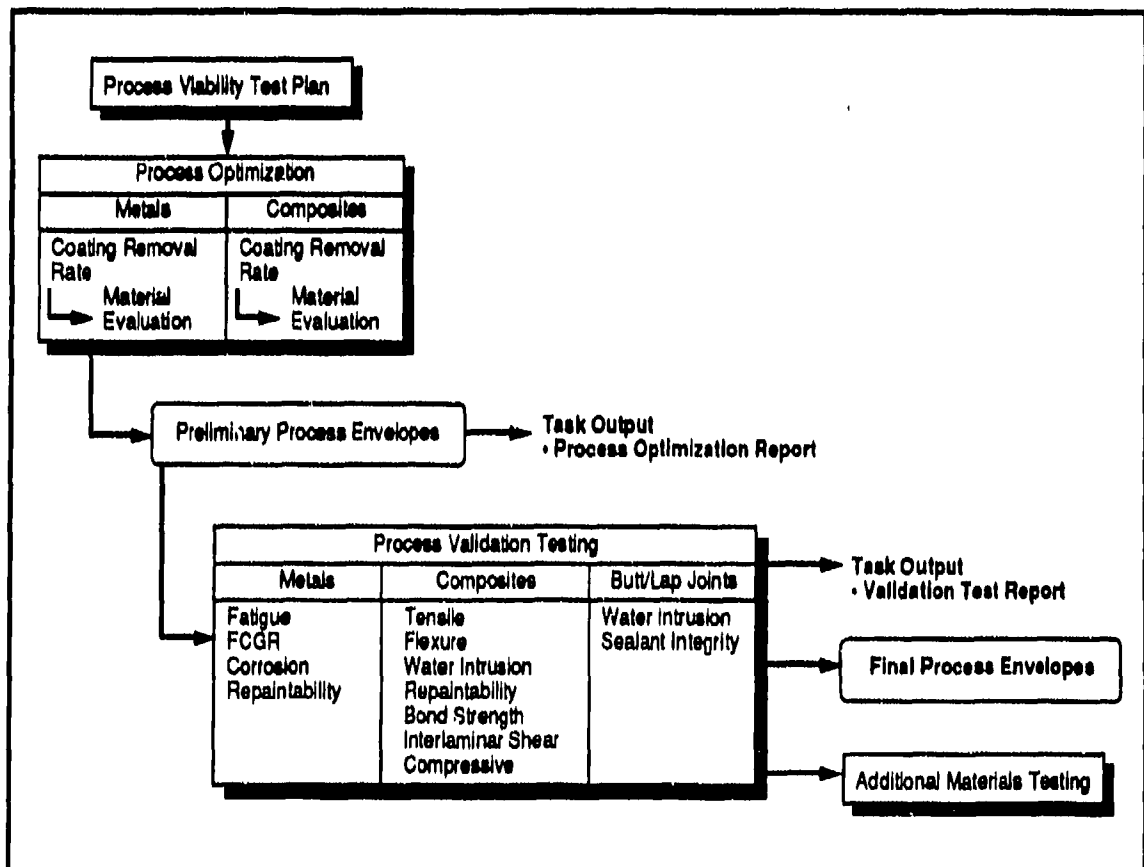


Figure 7. Process Optimization and Process Validation Testing Roadmap

in Figure 8. These nozzles increase the stripping efficiency of the topcoat and primer systems and significantly reduce the surface roughness by delivering the water at the threshold energy levels required to remove the coatings but not unacceptably roughen the underlying substrates.

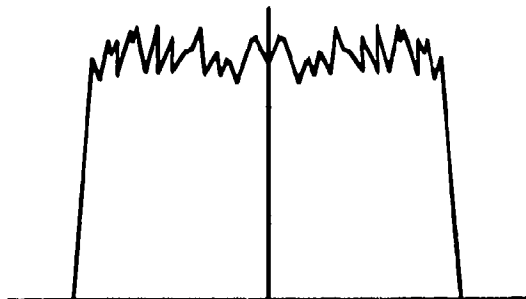


Figure 8. Waterjet Stripping Profile for High Pressure Waterjet Nozzle

The mechanism for coating removal is similar to the mechanisms for coating removal from rain erosion. However in contrast to the uncontrolled erosion and damage from rain impact, the flow dynamics and impact energies from high pressure water are controlled by the nozzle to increase the coating removal and not damage the substrates. Work is presently being performed by USBI to model the coating removal mechanism and identify coating properties which control the removal behavior. This model will allow process parameters to be selected based on coating characteristics in the field and relate the coating removal to waterjet impact energies.

The task structure for Process Optimization is shown in Figure 9. Initially, USBI performed a parametric evaluation using the critical process parameters of water pressure, stand-off distance, and nozzle travel speed to identify process envelopes for complete stripping. These candidate process envelopes were used to investigate residual stresses and surface roughness. The data from these tests were used to define the preliminary process envelopes and select a nozzle for further testing during Process Validation Testing.

Typical aircraft substrates and coating systems presently being chemically stripped at the OCALC were used. The substrates included Aluminum 2024-T3 clad and Aluminum 2024-T3 bare having a thickness of 0.032-inch. The coating systems were MIL-P-23377 epoxy primer/MIL-C-83286 polyurethane topcoat and Koroflex polyurethane primer (P/N 823X439)/MIL-C-83286 polyurethane topcoat. Although both coating systems were evaluated during this segment, the Koroflex primer/MIL-C-83286 topcoat has been

selected as the baseline coating system for the Process Validation Testing. This selection was based on the number of aircraft having the Koroflex primer compared to the MIL-P-23377 primer/MIL-C-83286 topcoat system as shown in Table 7 and projected work load for the LARPS system. The metals evaluation was performed using a 4.0-inch diameter nozzle designated as LN5.

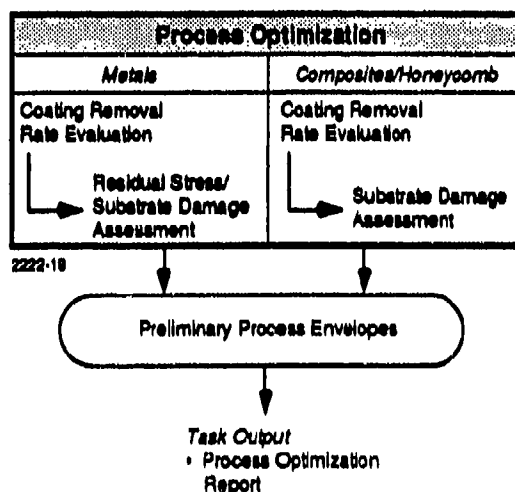


Figure 9. Process Optimization Task Structure

Table 7. Summary of Primer Systems for OCALC Aircraft Projected for LARPS Processing

Aircraft Type	Water based Solvent		Polyurethane	Koroflex	Unicoat
	Epoxy	Epoxy			
B1-B	10	85			
B-52G/H			65		71
E-3			35		
C-135 series	100	50	200	400	5

The following procedures were used for coupon cleaning, painting, and artificial aging and were developed based on current production and test procedures used by the Oklahoma City Air Logistics Center. The panels were:

- Cleaned using an alkaline detergent conforming to MIL-C-87936, Type I and scrubbed with a soft brush to remove surface dirt.
- Etched using a phosphoric acid solution conforming to MIL-C-38334 and scrubbed with a soft brush to remove surface oils or other contamination which can reduce coating adhesion.

- Coated with a chromate conversion coating conforming to MIL-C-81706. The coating was applied according to MIL-C-5541, and the excess coating removed using a water warm rinse.
- Coated to a dry film thickness of 0.6 to 0.9 mils with the Koroflex primer (P/N 823X439) or solvent based epoxy conforming to MIL-P-23377. The coating was allowed to air dry for one hour.
- Coated to a dry film thickness of 2.2 to 3.2 mils with a polyurethane topcoat conforming to MIL-C-83286. The coating was allowed to dry for a minimum of seven days at room temperature.
- Artificially aged using a post cure thermal cycle of 210°F for 96 hours.

The adhesion of the coating system to the substrates was checked prior to processing to insure adequate adhesion. The adhesion was tested according to ASTM D4541, Standard Test Method for Pull Off Strength of Coatings Using Portable Adhesion Tester.

A description of each procedure from Process Optimization is given in the following paragraphs:

Stripping Rate Evaluation

The objective of this procedure was to select the preliminary process parameters which produced the maximum stripping rate for the complete stripping of the coating systems. To minimize any panel to panel paint variations which could affect the selection of candidate process envelopes, multiple stripping passes were made on one panel. The critical process parameters for complete stripping evaluation are given in Table 8. The parameters producing the maximum stripping rate for complete stripping were chosen for further evaluation of residual stress and surface roughness.

Table 8. Critical Process Parameters for Complete Stripping

Pressure (psi)	Stand-Off Distance (inch)	Velocity (in/sec)
22,000	1.0	0.75
24,000	1.5	1.00
26,000		1.50
28,000		1.75
		2.00

Residual Stress Evaluation

The objective of this test was to determine the effects of the process parameters selected from the stripping rate evaluation on the residual stress of Al 2024-T3 bare substrate. The residual stresses were evaluated using Almen strips and procedures defined per SAE J440, Test Strip, Holder, and Gage for Shot Peening. The residual stresses were determined for one stripping cycle plus three simulated stripping cycles. For the first stripping cycle, the Almen strip was coated and for all subsequent stripping cycles, the Almen strip was unpainted. The arc height was measured after each stripping cycle. Ten Almen strips per process envelope were used. A goal of less than 5 mils was established by the OC-ALC Laboratory.

Surface Roughness Evaluation

The objective of this test was to determine the effects of the selected process parameters on the substrate integrity after processing. The surface roughness of Al 2024-T3 clad was measured using a Mitutoyo SurfTest profilometer.

USBI has completed the Process Optimization testing. Coating removal rates greater than 100 square feet per hour (1.8 square feet per minute) per nozzle have been demonstrated with arc height deflections of less than 3 mils after four stripping cycles. Surface roughnesses have shown acceptable values for the process envelopes for each coating system. The LN5 nozzle has been selected for processing coupons during the Process Validation Testing. A discussion of the LN5 test results is given in the following sections.

Coating Removal Rate

A coating removal rate evaluation was performed to identify the candidate process parameters which produced the highest stripping rate for the two coating systems being evaluated during Process Optimization. A summary of the stripping rates for the two coating systems is given in Table 9 and shows the significant difference in the stripping behavior of the coating systems. The MIL-P-23377 primer/MIL-C-83286 topcoat was more difficult to completely remove than the Koroflex (P/N 823X439) primer/MIL-C-83286 topcoat. This paint system required high water pressure, shorter stand-off distance, and slower nozzle speed to achieve complete stripping compared to the Koroflex system.

Table 9. Summary of Stripping Parameters for Coating Systems Using LN5 Nozzle

Coating System	Parameters for Complete Stripping	Stripping Rate
MIL-P-23377/ MIL-C-83286	• 28 ksi, 1.0 -inch, 0.8 in/sec	75 ft ² /hr (1.25 ft ² /min)
Koroflex/MIL- C-83286	• 24 ksi, 1.00 -inch, 1.75 in/sec	164 ft ² /hr (2.73 ft ² /min)
	• 24 ksi, 1.30 -inch, 1.25 in/sec	110 ft ² /hr (1.83 ft ² /min)
	• 24 ksi, 1.55 -inch, 1.25 in/sec	110 ft ² /hr (1.83 ft ² /min)

For the MIL-P-23377 primer/MIL-C-83286 topcoat, complete coating removal was achieved by processing at a water pressure of 28 ksi, a nozzle stand-off distance of 1.0 inches, and a nozzle travel speed of 0.8 inch/second. The test panel is shown in Photograph 1. The MIL-P-23377 primer forms a tenacious bond with the aluminum substrate which increases the difficulty in complete removal.

For the Koroflex primer/MIL-C-83286 topcoat system, three process envelopes were initially selected for complete stripping and are given in Table 9. More process envelopes were identified for the Koroflex/MIL-C-83286 system than the MIL-P-23377/MIL-C-83286 system since the Koroflex primer was easier to remove. Photograph 2 shows the Koroflex primer/MIL-C-83286 topcoat system removed from Al 2024-T3 alclad after processing at 24 ksi, 1.00-inch stand-off distance, and 1.75 inch per second. Photograph 3 shows the Koroflex primer/MIL-C-83286 topcoat system removed from Al 2024-T3 alclad after processing at 24 ksi; 1.4-inch, 1.45-inch, and 1.50-inch stand-off distances; and 1.25 inch per second. All paths show acceptable stripping. Photograph 4 shows the same system after processing at 24 ksi; 1.5-inch, 1.55-inch, and 1.60-inch stand-off distances; and 1.25 inch per second.

The upper limit on the stand-off distance is 1.6-inches. Based on robot design tolerances and the range for the stand-off distance for efficient paint stripping, the nominal stand-off distance was selected as 1.3-inch.

These process envelopes were used to evaluate the residual stresses and substrate integrity.



Photograph 1. Stripping Efficiency of MIL-P-2337 Primer/MIL-C-83286 Topcoat on AL 2024-T3 Alclad Processed at 18 ksi, 1.0-inch, and 0.8 inch/second



Photograph 2. Stripping Efficiency of Koroflex Primer/MIL-C-83286 Topcoat on Al 2024-T3 Alclad Processed at 24 ksi, 1.0-Inch Standoff Distance, and 1.75 Inch/second



Photograph 3. Stripping Efficiency of Koroflex Primer/MIL-C-83286 Topcoat on Al 2024-T3 Alclad Processed at 24 ksi, Varying Stand-Off Distances, and 1.25 Inch/second. Stand-Off Distance from Left to Right: 1.40-Inch, 1.45-Inch, and 1.50-Inch



Photograph 4. Stripping Efficiency of Koroflex Primer/MIL-C-83286 Topcoat on Al 2024-T3 Alclad Processed at 24 ksi, Varying Stand-Off Distances, and 1.25 Inch/second. Stand-Off Distance from Left to Right: 1.50-inch, 1.55-inch, and 1.60-inch

Residual Stress

Almen strips of Al 2024-T3 bare were processed at each of the process envelopes for MIL-P-23377 primer/MIL-C-83286 topcoat and Koroflex primer/MIL-C-83286 topcoat systems selected during stripping rate evaluations. The Almen strips were processed once to remove the paint system and then three additional times without repainting between the stripping cycles to create a worst case scenario.

For the MIL-C-23377 primer/MIL-C-83286 topcoat system, the Almen strips were processed at 28,000 psi, 1.0-inch standoff, and 0.8 inch/second nozzle speed. The arc height deflection as a function of the number of stripping cycles is shown in Figure 10. For this process envelope, the arc height did not exceed the Air Force goal of 3 mils for deflection. The largest increase occurred after the first pass. Although subsequent passes produced an increase after each pass, the change in the deflection is lower and suggests that a saturation point is being approached between 3 to 4 mils. Additional saturation studies have shown that the saturation limit is 4 mils.

For the Koroflex primer/MIL-C-83286 topcoat system, four process envelopes were selected for the residual stress evaluation and included:

- 24,000 psi, 1.0-inch, 1.75 inch/second
- 24,000 psi, 1.0-inch, 1.25-inch/second
- 24,000 psi, 1.3-inch, 1.25-inch/second
- 24,000 psi, 1.6-inch, 1.25-inch/second

Figure 11 shows the arc height deflection versus the number of passes for 24,000 psi, 1.0-inch, and 1.75 inch/second. Arc height deflections remain below the 3 mil goal for the four passes.

Figure 12 gives the deflection for the remaining three envelopes. From the stripping rate evaluation, the nominal process parameters were found to be 24,000 psi, 1.3 inch, and 1.25 inch/second. Because the nozzle stand-off tolerance for the robotic system will be ± 0.25 inch, the residual stresses at 1.0-inch and 1.6-inch were also investigated to cover the tolerance range. Similar arc height deflections were found. The arc height did not exceed the 3 mil goal.

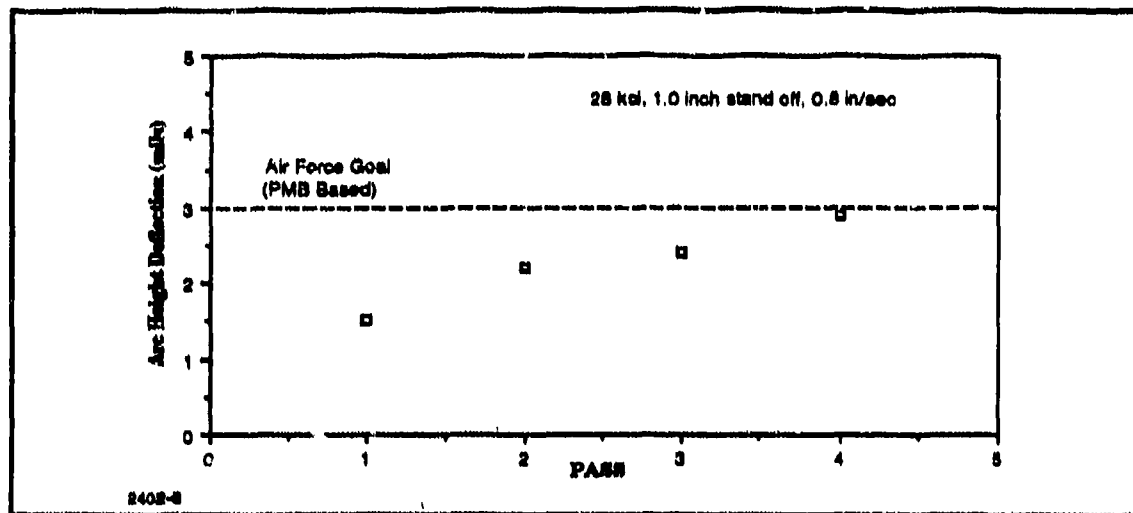


Figure 10. Arc Height Deflection Versus Number of Passes for MIL-P-23377 Primer/MIL-C-83286 Topcoat

Surface Roughness Evaluation

The effects of the selected process envelopes for complete stripping of the MIL-P-23377 primer/MIL-C-83286 topcoat and Koroflex primer/MIL-C-83286 topcoat systems on the substrate integrity were investigated by measuring the surface roughness of AL 2024-T3 alclad.

MIL-P-23377 Primer/MIL-C-83286 Topcoat

AL 2024-T3 alclad was processed 28,000 psi, 1.0-inch, and 0.8 inch/second for four passes. By the LARPS process test requirements, the nozzle was passed over the same area four passes. The first pass was made on a coated panel and the next three passes were made on the uncoated surface. This condition is worst case and is not anticipated in actual operations since the process is robotically controlled and the probability of the nozzle travelling over the exact area during successive passes is precluded by design.

Surface roughness measurements were made after each pass. The data is given in Table 10.

The surface roughness increases as the number of passes increases, especially when processing the surface with no coating. The alclad response to the high pressure water is related to the waterjet energy dissipation mechanism. During the coating removal, the waterjet impacts the surface and dissipates its energy by removing the coating, and only a small amount of energy

remains to react with the alclad layer as seen by the small increase in the surface roughness after the first pass. For passes 2-4, the waterjet impact energy is dissipated by deforming the alclad since there is no coating to absorb any impact energy. Consequently, selecting process parameters which provide the impact energy required to remove the coating but not damage the alclad surface is critical to the process optimization.

Table 10. Surface Roughness After Four Stripping Cycles at 28,000 psi, 1.0-inch, and 0.8-inch/second

Substrate	Pass No.	Roughness, Ra (micro-inch)
Al 2024-T3 alclad	1	37
	2	97
	3	243
	4	251

Al2024-T3 alclad was processed at 24,000 psi, 1.3-inch, and 1.25 inch/second for four passes similar to the MIL-P-23377 primer/MIL-C-83286 topcoat coupons. Surface roughness measurements were made after each pass. The data is given in Table 11.

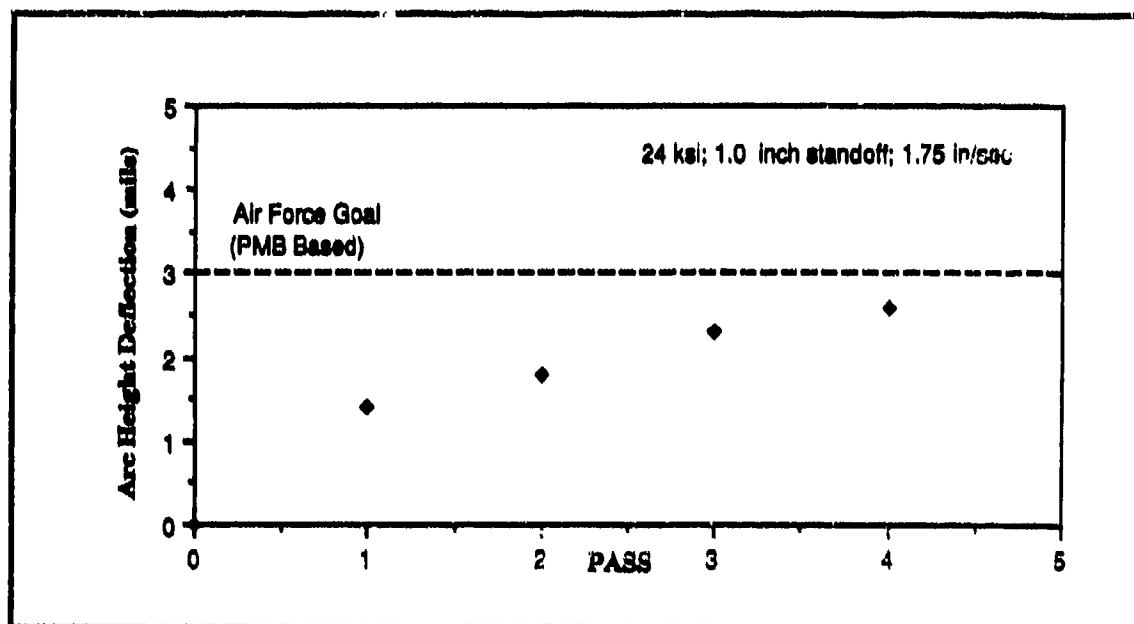


Figure 11. Arc Height Deflection Versus Number of Passes for Koroflex Primer/MIL-C-83286 Topcoat Processed at 24000 psi, 1.0-Inch, and 1.75-Inch/second

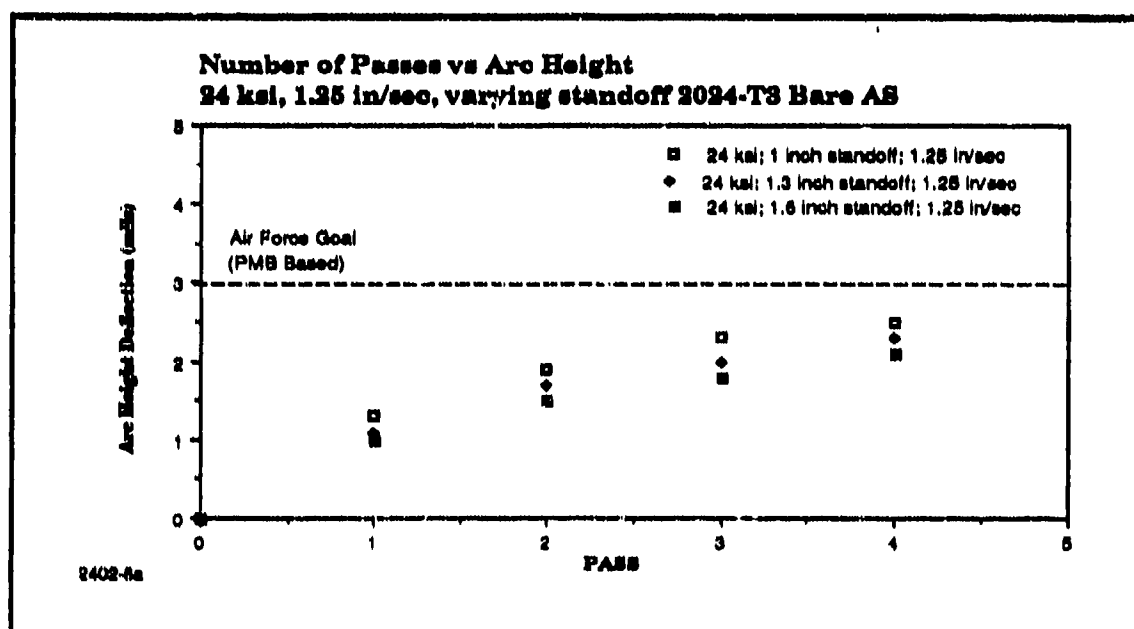


Figure 12. Arc Height Deflection Versus Number of Passes for Koroflex Primer/MIL-C-83286 Topcoat Processed at 24000 psi, Varying Stand-Off Distances, and 1.25 Inch/second. Standoff Distance of 1.0-Inch, 1.3-Inch, and 1.60-Inch

Table 11. Surface Roughness After Four Stripping Cycles at 24,000 psi, 1.3-Inch, and 1.25-Inch/second

Substrate	Pass No.	Roughness, Ra (micro-inch)
Al 2024-T3 alclad	1	23
	2	36
	3	67
	4	126

Because of the lower impact energies from the waterjet due to the lower water pressure, the increase in the surface roughness was not as great as for the MIL-P-23377 primer/MIL-C-83286 topcoat system.

The Process Validation Testing plans are shown in Table 12. An extensive materials evaluation will be performed to characterize the effects of the high pressure water on the mechanical properties of metals, composites, and joint/fastener panels. The metallic substrates to be investigated will include Al 2024-T3 alclad, Al 2024-T3 bare, Al 7075-T6 alclad, and Al 7075-T6 bare. The composite substrates will include graphite/epoxy, fiberglass/epoxy, graphite/epoxy faced aluminum honeycomb, fiberglass/epoxy faced aluminum honeycomb, and aluminum faced aluminum honeycomb. The panels will include butt joints, lap joints, and fastener panels having various rivets, cherry locks, and jo-bolts combinations. These panels will be used to investigate sealant integrity and water intrusion.

CONCLUSION

In conclusion, the LARPS system has a unique character—to successfully automate day-to-day paint removal operations using an alternative removal process.

In addition to automating paint removal operations, inspection and painting of aircraft are two other operational areas which could benefit from a LARPS type system with a minimum of additional development work (and cost). Inspection techniques such as X-ray, ultrasonic, dye penetrant, eddy current, infrared or computer aided tomography could be easily adapted for automated operations. Automating some of these operations could eliminate workers from tedious tasks such as looking at their thousandth rivet at two o'clock in the morning. In addition, greater accuracy and process controls would result.

Painting operations, while not requiring excessive cycle time, could be assisted in the areas of

quality and consistency by an automated system. Additionally, a LARPS type system would eliminate workers from solvent inhalation and flammable hazards.

LARPS successful implementation will provide not only a solution for OC-ALC's environmental efforts, but also a platform from which to meet the aircraft exterior refurbishment requirements for broader military and commercial aviation applications.

The High Pressure Water Process Optimization for metals has been completed, and the feasibility of the high pressure water process to completely remove the coating systems has been successfully demonstrated. The results have been approved by the United States Air Force. Approval to proceed with Process Validation Testing has been received and work is underway.

For the high pressure water process, parameters have been selected to remove the MIL-P-23377 primer/MIL-C-83286 topcoat and Koroflex primer/MIL-C-83286 topcoat systems. For the former system, a stripping rate of 1.25 square feet per minute per nozzle was achieved at 28,000 psi, 1.0-inch stand-off, and 0.8-inch per second nozzle travel speed. For the latter system, a stripping rate of 1.8 square feet per minute per nozzle was achieved at 24,000 psi, 1.3-inch stand-off, and 1.25-inch per second nozzle travel speed. The Koroflex primer/MIL-C-83286 topcoat system has been selected as the baseline coating system due to the number of aircraft having this coating system and the projected workload for the LARPS system. Process Validation Testing is currently being performed using the processing envelope for Koroflex primer/MIL-C-83286 topcoat system.

Program risk has been significantly reduced because of the successful accomplishments of the first phase of this important program. Its importance spans the productivity enhancement and cost reduction realms while offering, potentially, the most important breakthrough of the last two decades in helping to reduce the world's environmental hazards.

Table 12. Process Validation Testing Matrix

MATERIAL COUPON DESCRIPTION																
TEST SEGMENT	TEST DESCRIPTION	Al 2024-T3 clad	Al 2024-T3 bare	Al 7075-T6 clad	Al 7075-T6 bare	Fiberglass/Epoxy	Graphite/Epoxy	Al honeycomb(1)	Al honeycomb(2)	Al honeycomb(3)	Butt Joint Panel	Lap Joint Panel	Fastener Panel	A/C panel	Electric wire	
PROCESS VALIDATION Establish technology base for design and validate effects of each new (selected) process on structural properties of baseline substrate.	1 Fatigue life: baseline/unnotched: 100,000 cycles	25	25	25	25											
	2 Fatigue life: baseline/unnotched: 500,000 cycles	25	25	25	25											
	3 Fatigue life: baseline-notch/front: 100,000 cycles	25	23	25	25											
	4 Fatigue life: baseline-notch/back: 100,000 cycles	25	25	25	25											
	5 Fatigue life: processed-unnotched: 100,000 cycles	15	15	15	15											
	6 Fatigue life: processed-unnotched: 500,000 cycles	15	15	15	15											
	7 Fatigue life: processed-notch/front: 100,000 cycles	15	15	15	15											
	8 Fatigue life: processed-notch/back: 100,000 cycles	15	15	15	15											
	9 FCGR: baseline/HPW/Chemical	30	30	30	30											
	10 Corrosion: baseline/HPW/Chemical	24	24	24	24											
	11 Tensile Strength/Modulus: baseline/HPW					60	60									
	12 Flexural Strength/Modulus: baseline/HPW					20	20									
	13 Sealant Integrity										9	9				
	14 Bond Strength Integrity: baseline/HPW							20	20	20						
	15 Water Intrusion: baseline/HPW							3	3	3	9	9	3			
	16 Reproducibility: baseline/HPW	5	5	5	5			5	5	5						
	17 NDI-Ultrasonics: baseline/HPW					3		3	3	3						
	18 Water Absorption: baseline/HPW					5										
	19 Interlaminar Shear Strength: baseline/HPW					20	20									
	20 End Cap Modified Compression Properties: baseline/HPW					20	20									
	21 Flexural Properties of Sandwich Constructions: baseline/HPW							20	20	20						
	22 Damage Assessment					20	20	20	20	20	9	9	3			
	23 Microscopy SEM/Optical		A/R	A/R	A/R	A/R	A/T	A/R	A/h	A/R	A/R				A/R	A/R

NOTE

NUMBER OF COUPONS SHOWN IN MATRIX IS REQUIRED TO EVALUATE PROCESS EFFECTS. NUMBER OF COUPONS PREPARED AND REQUIRED FOR TEST SETUP IS NOT INCLUDED.

AUTOMATED LASER PAINT STRIPPING (ALPS) UPDATE

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1. INTRODUCTION

To date, chemical strippers are generally used to remove coatings from defense and commercial aircraft. The use of these strippers is problematical because of environmental impact, costs, and operational difficulties.

The use of methylene chloride/phenolic-type strippers has become unpopular or disallowed due to stringent controls national and local requirements. In post stripping, both the chemical stripper and the paint residue are highly toxic. They require a treatment cycle to separate toxic elements from those that are harmless. Once separated, the toxic elements must be collected and contained for disposal.

The costs associated with chemical paint stripping are astronomical. The process is labor intensive, taking from 500 to 1000 hours for fighter-sized aircraft and as much as 2000 hours for larger aircraft. Operational costs include special safety apparel, the cost of waste containment and disposal and facility/equipment maintenance costs. The entire stripping operation runs approximately \$32.60/ft² including materials, aircraft preparation and stripping, post-stripping clean-up, and inspection and maintenance.

Operational difficulties vary with different types of aircraft and impact stripping time. This includes up to three chemical applications to remove the coatings, and a large degree of hand sanding in areas where the coatings remain after chemical stripping. Another difficulty exists because chemical strippers degrade the composite resins and are, for the most part, not used in these areas. As a result, these areas must be masked during stripping and then demasked and sanded down to the primer for repaint.

It becomes obvious that a method other than chemical stripping is required to remove coatings from aircraft. Over the past twenty years, both the Department of Defense (DoD)

and commercial aircraft companies have been evaluating a number of new technologies to replace chemicals. The technologies include laser stripping, water jet, dry-ice crystals, plastic bead blasting, and bicarbonate blasting, to name just a few.

The requirements for a non-chemical stripping system are that it be nontoxic, be as fast as chemical stripping, have the ability to remove coatings from metal and composite, not initiate corrosion or otherwise damage the substrate, not effect repaint adherence, and must have a minimum clean-up cost and a low life cycle cost.

To date, the DoD has played a major role in funding a number of paint stripping programs. Some technologies have proven less effective than contemplated. Others are still in the validation phase. Paint stripping is one of the hottest issues being addressed by the finishing industry since the Environmental Protection Agency (EPA) has mandated that chemical stripping using methylene chloride/phenolic-type strippers be stopped. The DoD and commercial aircraft companies are hard-pressed to find an alternative.

2. DISCUSSION

Automated laser paint stripping has been identified as a technique for removing coatings from aircraft surfaces. International Technical Associates (InTA) was awarded a Navy contract for an automated laser paint stripping system (ALPS) that will remove paint from metallic and composite substrates. For the program, which will validate laser paint stripping, InTA will design, build, test, and install a system for fighter-sized aircraft at both the Norfolk and North Island (San Diego) Aviation Depots.

The program is divided into four phases:

Phase I:	Validation testing and parametrization
----------	----------------------------------------

- Phase II: Engineering Design
- Phase III: System Fabrication and Factory Acceptance
- Phase IV: Installation, Testing, Training, and Final Acceptance

3. AUTOMATED LASER PAINT STRIPPING CELL

3.1 System Requirements

After a detailed analysis of fighter-sized aircraft configuration, substrates and coating schemes, the following system requirements were established.

- Must have ability to strip 3-5 ft²/minute
- Must strip coatings from both metals and composites without degradation to substrate
- Must have the maneuverability and reach to access the major areas of an F-14, F-18, AV-8B, F-4, A-6, and other fixed or rotary winged aircraft.
- Must be capable of controlling contaminants which may emanate from the process
- Must be outfitted with safety systems/interlocks for both perimeter and cell safety.

3.2 Cell Configuration

The cell, which was conceived to satisfy the above requirements, consists of the following eight major elements (see Figure 1).

- Laser
- Robot
- Multi Spectral Camera
- Rastering System
- End Effector
- Waste Management System
- Cell Controller
- Safety System

A description of each system element follows.

Laser - The InTA approach to ALPS is best described by starting with the actual removal of paint. After an exhaustive investigation, pulsed CO₂ laser radiation with a peak power of 200-300 kW/cm² was found to be optimum. The process, as proposed, must have the ability to remove between 150 and 300 microinches of coating per pulse depending on

the type of coating. To achieve this power density on a square shaped pulse 1.1 cm on a side requires a 30 microsecond long, 6 joule pulse.

InTA chose United Technologies Industrial Laser Division (UTIL) as a program team member to develop a laser that would meet our performance requirements (see Table 1).

The laser (see Figure 2) is a pulsed adaptation of the continuous wave CO₂ industrial laser modified to incorporate UV pre-ionized CO₂ TEA laser technology, developed by United Technologies Research Center. An articulated beam delivery system, designed by InTA, will be used to transport the laser beam from the laser to the end effector. UTIL expertise will be applied to assure the beam delivery coincides with the pertinent elements necessary for laser beam transport over a fifty foot length.

Table 1 - Laser Performance Requirements

Parameter	InTA Spec
Output power	6 kW
Pulse repetition frequency	1000 Hz
Pulse energy	6 J
Pulse width	30 μ s (FWHM)
Pulse power (Peak, averaged over pulse)	300 kW
Pulse energy repeatability	$\pm 5\%$
Pulse timing repeatability	200 ns

Robot - To reach all parts of the aircraft requires a robot with ample maneuverability and reach. A gantry robot is good from the top but is greatly restricted in reaching under the aircraft. Wall mounted systems would require a reach that would exceed the mechanical limits for our repeatability requirements. A platform mounted system, on the other hand, has the capability of reaching all areas of the aircraft with the additional benefit of carrying the laser and other subsystems along with it.

After a competitive bidding process, InTA chose Vadeko as the robot supplier. Their

successful experience in developing large scale speciality robots coupled with expertise in aircraft applications will benefit the program in delivering a robust system.

The robot (see Figure 3) is a track mounted, pedestal type with seven degrees of freedom. Because of its modularity, it may be re-configured to address larger aircraft in future applications.

Multispectral Camera - A feed back loop is necessary to decide if the laser should be pulsed at a given location to remove a coating. A spectrograph - an instrument that divides light into different colors, is used to examine the color of the surface before the laser is fired. Colors can range from near ultraviolet to near infrared and includes all visible wavelengths. The spectra of colors to be removed are stored in a computer and compared to the spectra from the coating. If they match, the laser is pulsed, a small amount of paint removed, and the color is re-examined. This process continues until the color no longer matches the one stored in the computer. Figure 4 shows the spectral system concept.

Rastering System - Rather than working on one area to remove all the paint, the laser completely processes a larger area, called a frame, before returning to process any location again. This is called "rastering". The raster pattern covers a 30 by 30 centimeter area, the frame, that consists of 30 rows by 30 columns (see Figure 5). Rastering allows each area to cool before being processed again, which is especially important for coatings like sealants or when removing coatings from composite substrates. Once a frame is clean of any color paint whose spectra was stored in the computer, the system commands the robot to move to a new frame.

The aircraft to be stripped is mapped into a series of paths consisting of adjacent frames. To ensure that all the paint on the aircraft is removed and no lines or bands of paint remain between frames, the frames are overlapped, which removes the need for a precision robot. The merging between frames is accomplished using the feedback system discussed above.

End Effector - The end effector houses the rastering system, the spectrometer, the waste

evacuation tube, and the air knife for optics protection. Attached to the housing is a reconfigurable, flexible hood that traps the effluents and, through the use of a second air knife, forces the effluents into the waste evacuation tube. The end effector housing is 2 ft³ with the flexible hood extending another 18 inches (see Figure 6).

Waste Management System - The material removed from the aircraft is vacuumed up as it is created and sent through the waste evacuation tube located on the end effector, to a waste processor which separates the waste into particulate material and vapors. The particulates are filtered out, dried, and placed in storage containers. The vapors are oxidized and converted to carbon dioxide, nitrogen and water vapor. This system (see Figure 7) meets federal, state, and local laws.

Cell Controller - The initial design of the control system architecture has been developed (Figure 3). The control system consists of a workcell controller responsible for the entire process operation. It will be implemented on a VME-bus based computer with a real-time UNIX operating system. Multitasking and multiprocessor UNIX capability will allow control of the I/O system and the laser safety system. It will interface to the robot controller and the operator interface computer. The operator interface computer and the simulation workstation will be in the operator control room, but the real time computers will be located inside the workcell, on the cart.

Safety System - The safety system will provide a class I laser enclosure insuring both personnel and facility safety. The principal hazards are those associated with the robot, movement of aircraft into and from the work cell, and the high-power laser system.

The ALPS system operates automatically under the supervision of an operator in a control booth overlooking the work area. The operator is never exposed to risk during operation. The greatest risk to personnel, equipment, and facilities occurs during servicing and maintenance. The ALPS work cell incorporates numerous safety features to mitigate risks during operation, service and maintenance.

Emergency stop switches establish laser, robot motion and high-voltage safety. They do not depend on normal functioning of logic shutdown circuits. The emergency stop switches are located on each side of the aircraft entry door; adjacent to every personnel exit door; along all walls at no more than 20-foot intervals and on the operator's console. The switches are wired in series to form two independent series chains, one for laser interlocking and one for robot interlocking. The laser interlock chains disables AC line power to the laser high-voltage power supplies. The robot interlock chain disables AC line power to the robot servo amplifiers. Control computer power is not affected by the emergency stop interlock switches. The laser high-voltage capacitors are discharged within 10 seconds after activation of an emergency stop switch.

The ALPS system utilizes a repetitively pulsed, transverse-flow, electric-discharged-pumped, carbon-dioxide laser of approximately 6 kilowatts average power. This laser is classified as Class IV under regulations of the Federal Center for Devices and Radiological Health (CDRH), the Federal Laser Product Performance Standard (FLPPS), and under the "American National Standard for the Safe Use of Lasers" of the American National Standards Institute (ANSI Z136.1). Class IV CO₂ lasers are hazardous to eyes and skin, but because of the rapid divergence of the laser beam beyond the working surface, the beam drops below hazard level at approximately 20 feet from the working surface. Nonetheless, the workcell will be interlocking to define and limit the nominal hazard zone (NHZ) to the interior of the work cell. Aside from providing light-tight closure of all access to the cell, interlocking of access doors and panels and installation of warning signs, lights, etc., the inside perimeter of the work cell must also be protected from fire ignition or burn-through, should a malfunction occur.

ALPS operates under the supervision of a trained operator and a control computer programmed to recognize most failure modes. However, we cannot assure that some unanticipated malfunction cannot occur simultaneously with a period of operator inattention. Accordingly, the ALPS work cell

walls must contain the ALPS laser beam for not less than five minutes during normal operation. In order to meet this requirement, the cell walls are of fire resistant construction of four layers of 5/8-inch type "X" gypsum board on studs (2 layers on each side) with the seams staggered and taped. The interior ceiling consists of two layers of 5/8-inch type "X" gypsum board, with the seams staggered and taped, and both walls and ceiling are painted with paint that resists vertical flame spread.

Laser operation with the optics in place presents low total irradiance due to the divergence of the laser beam and the scanning pattern. However, if the optics are removed for maintenance, the laser irradiance may be much higher.

Servicing functions are those performed routinely to maintain efficient, safe operation of the ALPS system. No optics are to be removed from the ALPS system during servicing. If optics servicing is required, such as cleaning of optical surfaces, this shall be done with the laser shut down. Thus servicing presents no optical containment requirements above those experienced in routine operation. Also, routine power measures involve no exposed laser beams. Laser power measures are taken internally to the laser output optics housing. These measurements present no hazard to personnel. System maintenance, the correction of failures, present much greater hazards, because optic elements and/or beam enclosures may be removed. Beam radiances of a kilowatt/sq. cm or more are possible. Mitigating factors and requirements are the following:

Maintenance personnel are trained in the hazards and in proper techniques for aligning and testing high-power lasers.

Optical alignment is performed with a low-power visible laser. There should be no requirement for operation of the high power ALPS laser except in final check-out.

All laser maintenance (and most robot maintenance) shall be performed in a dedicated maintenance area of the robot track. This area shall be warning striped.

Temporary barriers are used to limit the propagation of laser beams from the

maintenance area. These barriers are movable as required, and are signed per ANSI Z 136.1 requirements. The robot operates under computer control. It has the potential to cause injury to personnel if in the work cell while it is operating. Specific work rules are enforced and safety features implemented to preclude accidents. The robot is rail mounted, so its path of travel and the reach of its arm are both limited and readily apparent to trained personnel. A yellow safety stripe is painted on the floor enclosing the area swept by the robot and its arm. Personnel standing outside that stripe will be in no danger from robot motion. During normal operation personnel are excluded from the work cell when the robot servo amplifiers are enabled. During pauses in operation, personnel may enter the work cell provided the robot servo amplifiers are disabled and at least two trained operators are present. The robot has a flashing red light that is operating at all times the robot servo amplifiers are enabled. A warning horn sounds for ten seconds before each time the robot servo amplifiers are enabled. A warning horn located on the robot sounds continuously while the robot is moving on its rails. No warning horn is required when the robot is moving only its arm or end effector.

During service and maintenance there will be requirements to work on the robot with the servo amplifiers enabled. Such work requires appropriate safety precautions including the following:

- Observance of two-person work rules
- higher level of training than required for operation
- shutdown of the laser if not required for the maintenance being performed.

Unless required otherwise, service and maintenance shall be performed only with the robot parked in the designated maintenance area of the work cell and with its wheels chocked to preclude motion along the rails. The floor area within reach of the robot arm in the maintenance area is pre-stripped to facilitate recognition of the hazard.

4. PROGRAM PROGRESS TO DATE

4.1 Phase I

Phase I was split into several subphases in order to prove the feasibility of laser paint stripping without unnecessary risk. Phase Ia

and Ia-supplemental demonstrated the basic viability of the process on a small matrix of substrates and coatings. Phase Ib will examine the effects of the process on a wide range of substrates and coatings (Table 2). Because the Navy had concerns about possible excessive temperature rise when stripping composites, it was decided that a small number of composite panels would be stripped and tested before the majority of composite panels were stripped. This was to be done in order to determine a maximum safe stripping rate for the composites.

To date, all the four strip cycle aluminum, titanium, and 17-4PH stainless steel substrates have been stripped. The Phase Ib-supplemental temperature rise tests data has been obtained. The initial composite test panels will be stripped once the temperature rise data is reduced, analyzed, and a report submitted and approved by the Navy.

4.2 Phase II

Phase II, System Design, was started on November 15, 1991, culminating in a Critical Design Review. Phase II was started before Phase I was completed because the initial material stripping and analysis (Phase Ia) suggested the process validation would be successful.

The design phase has been divided into ten major elements, as follows:

- Robot
- Laser
- End Effector
- Spectral Camera System
- Waste Management System
- Power Distribution
- System Safety
- Control System
- Modeling/Simulation
- Software

Major components have been chosen with prototyping of pertinent subsystems scheduled soon thereafter.

4.3 What's next

Phase III, system fabrication, will commence once Phase II is satisfactorily complete. The phase is fourteen months long and will result in an ALPS System being ready for installation in each of the two depots.

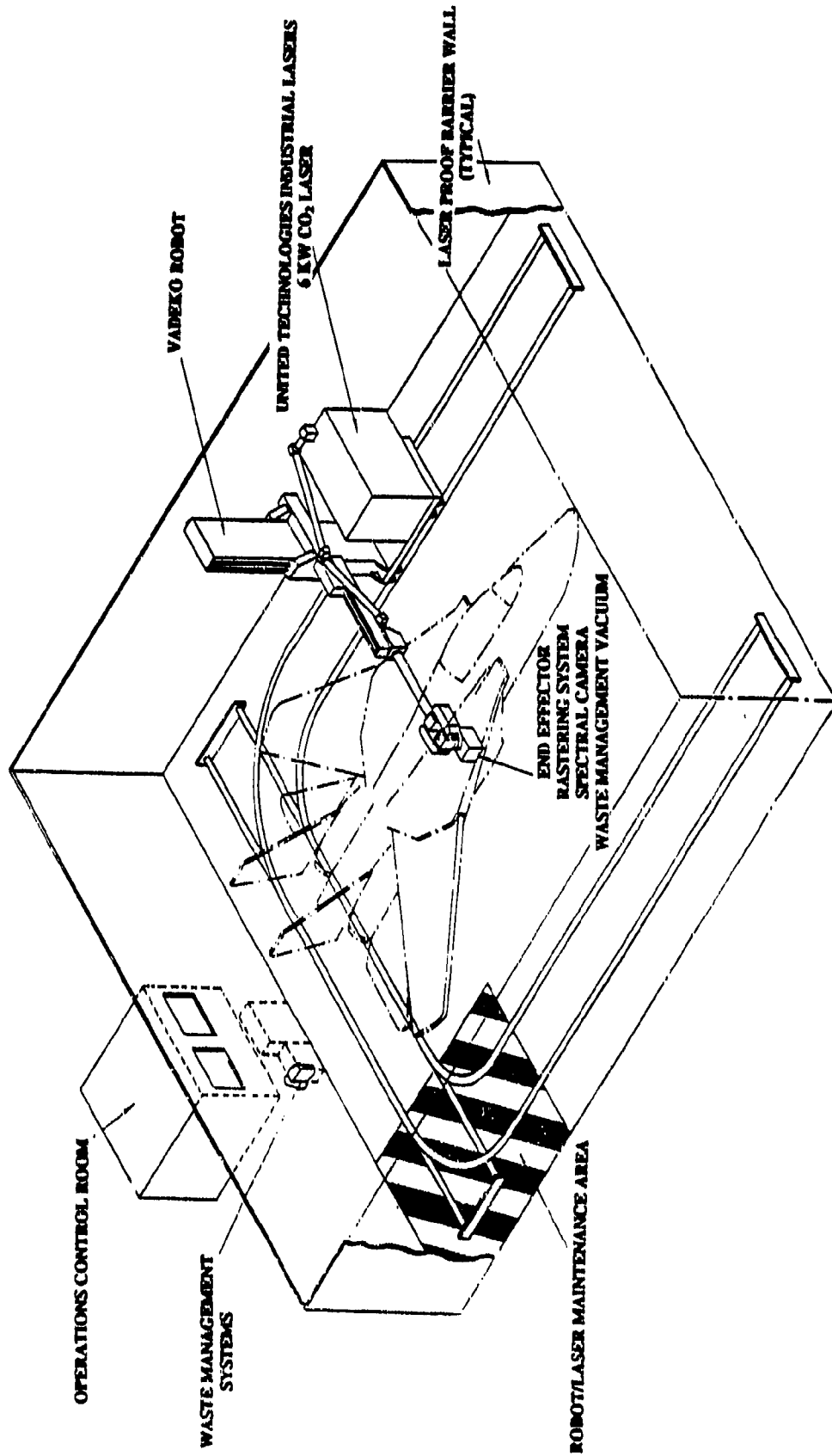


FIGURE 1 - CELL LAYOUT

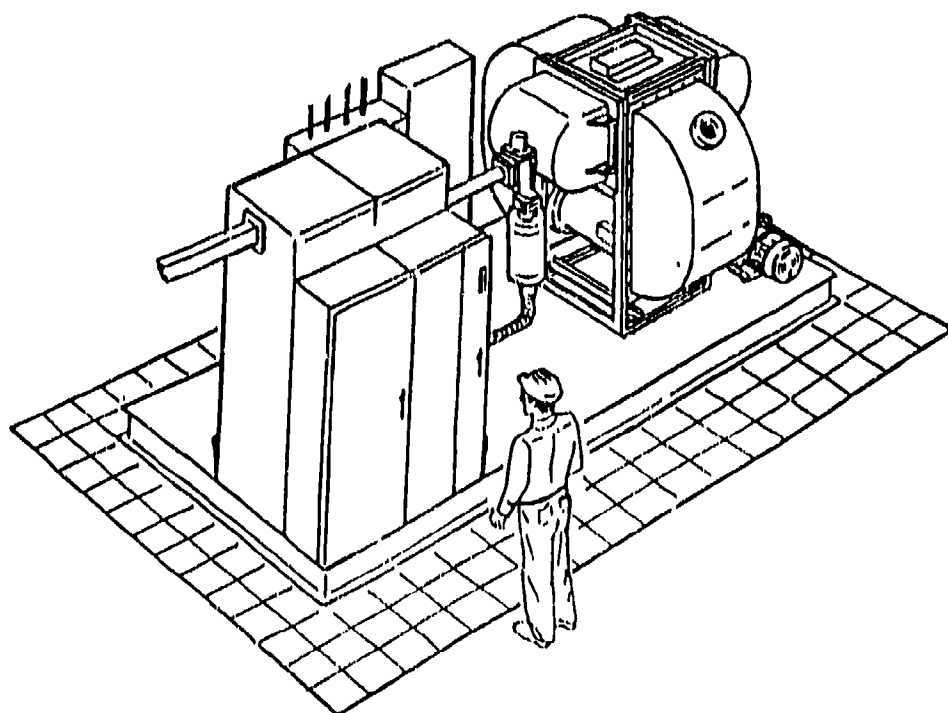


FIGURE 2 - UTIL LASER

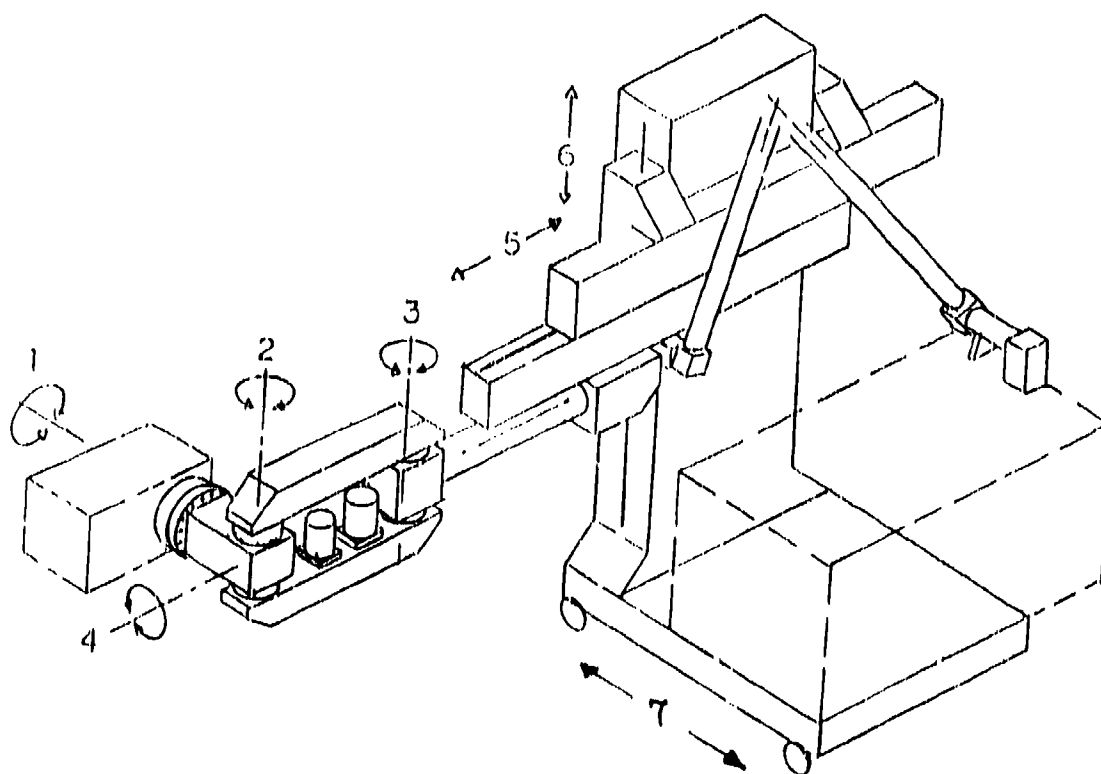


FIGURE 3 - ROBOT

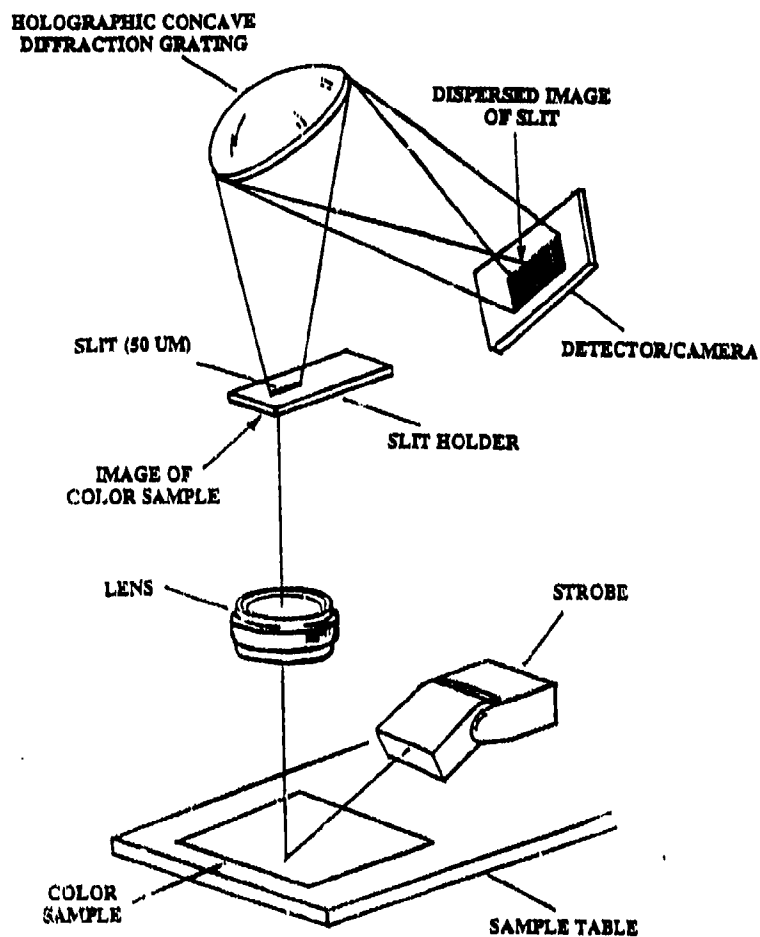
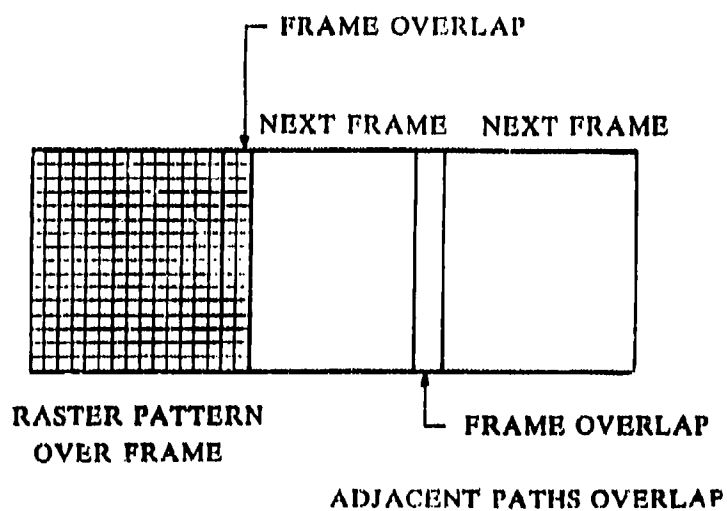


FIGURE 4 - MULTI-SPECTRAL CAMERA



PATH COMPOSED OF FRAMES

FIGURE 5 - RASTER FRAMES

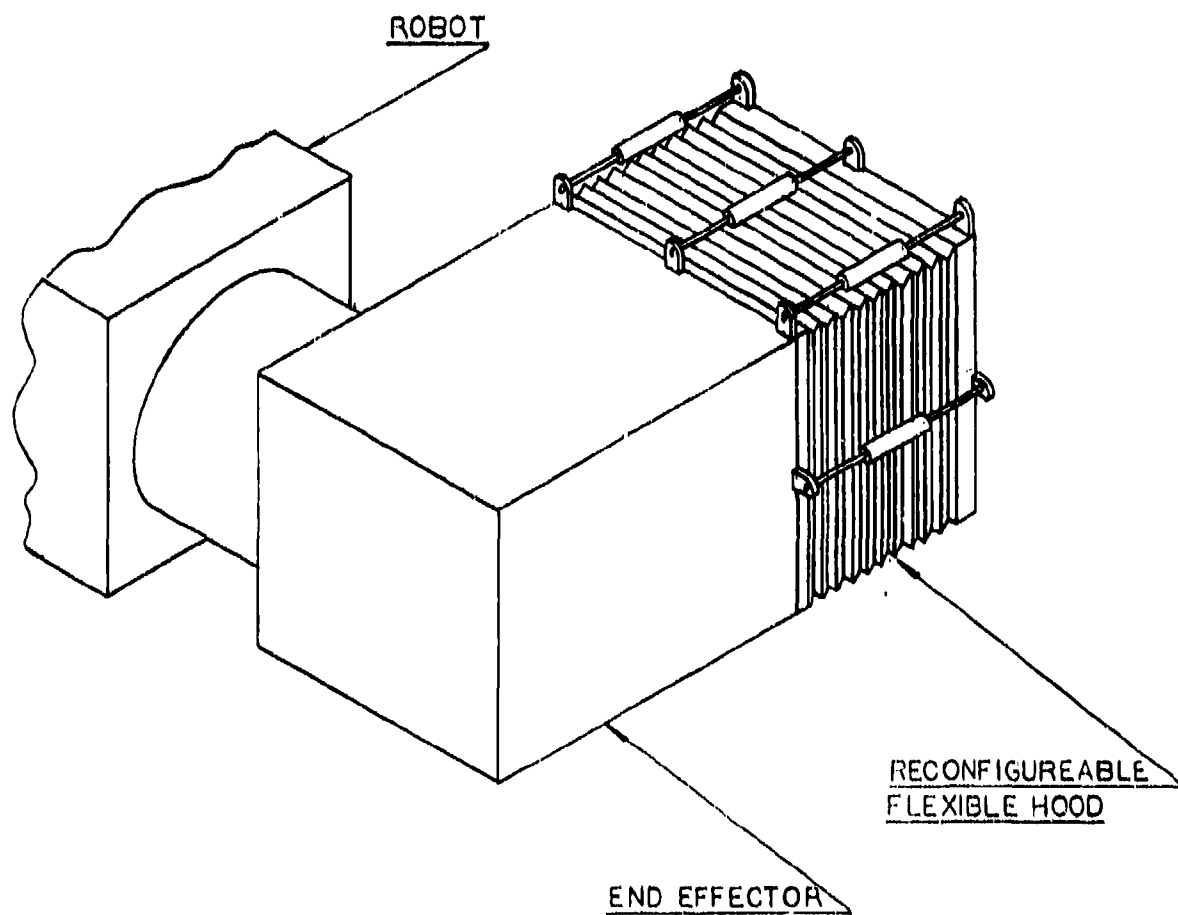


FIGURE 6 - END EFFECTOR CONFIGURATION

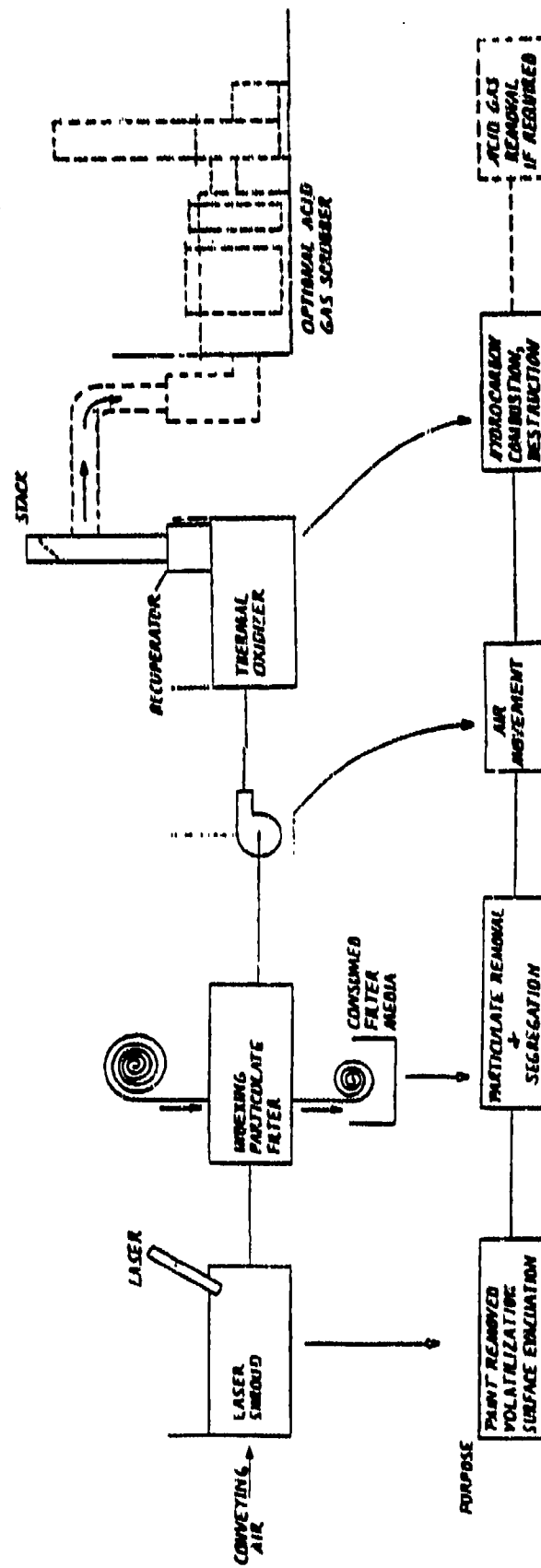


FIGURE 7 - WASTE MANAGEMENT SYSTEM

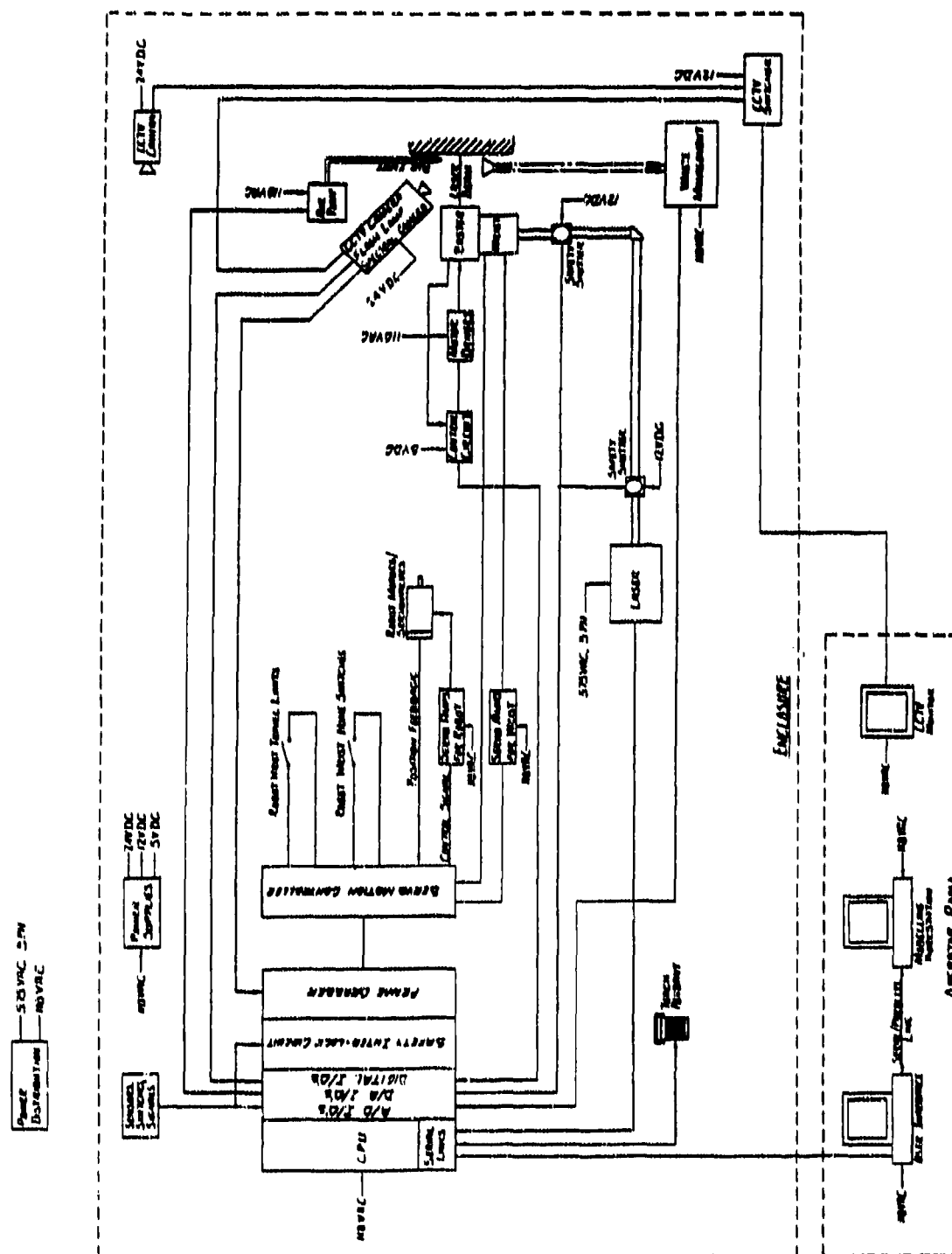


FIGURE 8 - CONTROL SYSTEM ARCHITECTURE

Table 2a - Phase Ib Test Matrix, List of Substrate Materials

Aluminum	Steel
7075	D6AC .187" Thick
T6C .016" Thick	17-7PH TH1050
T6B .063" Thick	Metal-Metal
T6B .063" Thick Riveted	Composites
2024	FIBERGLASS/EPOXY(GH4001)
T3B .016" Thick	GRAPHITE/EPOXY(AS4,3501-G)
T3C .063" Thick	GRAPHITE BMI V378
T81C .032" Thick	GRAPHITE(AS4 FABRIC)
T81B .032" Thick	GRAPHITE(IM6 TAPE)
Titanium	KEVLAR 49/EPOXY
6AL-4V .030"	FIBERGLASS/EPOXY(GH3006)
6-6-2 .030"	

Table 2b - Phase Ib Test Matrix, List of Pretreatments and Coating Systems

Pretreatments	Coatings
Grind and Cadmium Plating	Epoxy Primer Polyurethane Topcoat
Chromic Acid Anodize	Koroflex Primer Polyurethane Topcoat
Sulfuric Acid Anodize	Water Bourne Epoxy Primer Walkway
Dry Hone and Pasagel	Coating
Light Scuff Sand	Epoxy Primer Rain Erosion Coating
	Epoxy Primer Chemical Agent
	Resistant Coating Erosion Guard
	(Polyurethane/Adhesive)

Table 2c - Phase Ib Test Matrix, List of Tests

Metallurgy:	Composites:
Tensile Testing	Moisture Absorption
Fatigue Testing	4-Point Flexure
T-Peel	C-Scan
Surface Roughness	Paint Adhesion
Salt Spray	Fiberglass
Paint Adhesion	GH 4001
Conductivity	GH 3006
Cross-Section	Graphite/Epoxy
Fractography	AS4,3501-6
	BMI V378
	AS4 Fabric
	IM6 Tape
	Kevlar/Epoxy
	49

Notes:

Paint Adhesion Test done per Federal Test Standard No. 141B

Salt Spray (FOG) Test done per ASTM B117-73

Crack Growth Test done per ASTM E647-86

Fatigue Testing done per ASTM E466-82

T-Peel Testing done per ANSI/ASTM D1876-72

Static Flexure and Short Beam Shear Tests done per Grumman Spec. No. GM3017B

Static Flexure and Short Beam Shear Tests done with the blasted side in both tension and compression

"AquaStrip® -An innovative paint removal technology-"

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SUMMARY

Environmental, safety and health issues, forced operators to search for an alternative paint removal process. High pressure water jetting and new integrated paint & stripper systems are LUFTHANSA's answer to this challenge. AQUASTRIP complies with the specification requirements. In order to receive approval from airframe manufacturers and authorities the process has undergone an extensive research program since 1988. An operation window was established, to enable maximum of safety during operation on metal and composite surfaces. Even though AQUASTRIP is a hybrid process and requires technological investment, it is well on the way to prove its innovative, ecological and economical character in first large scale applications under realistic conditions. Its potential has already been reflected by patents and trademarks, which were registered in conjunction with the development of AQUASTRIP and the vital interest for cooperative work on the process development and other potential utilization.

1. INTRODUCTION

Why was Lufthansa thinking about alternatives?

A new paint hangar at LUFTHANSA's overhaul base at Hamburg opened in February 1992. It has a potential capacity of 100 aircraft per year. If the hangar is fully utilized a total surface of approximately 100000 m² would be stripped and repainted. Based on classical chemical paint removal processes, nearly 250 tons of stripper would be used within a year. The amount of material to be disposed of would be even higher.

Neither ecological nor economical consequences of the classical chemical paint removal process could be ignored. The design and operation of the new hangar had to meet strict legal requirements of German authorities with regard to environmental and occupational health regulations. In this connection the technical expenditure would have been enormous. Furthermore, continuously increasing disposal costs had to be taken into account.

The commitment to ban the classical chemical stripping method from the operation in the new paint hangar required a serious investigation of alternative paint removal technologies.

2. ASSESSMENT OF ALTERNATIVE PAINT REMOVAL TECHNOLOGIES.

2.1 General Operational Requirements.

Which are the general process requirements?

The objective was to find a process which is in compliance with both the basic and LUFTHANSA's specific requirements:

- No phenol
- No chlorinated hydrocarbons (e.g. methylene-chloride)
- Environmentally sound
- No health hazard
- Dustless operation
- No deterioration of aircraft structure
- Applicable on commonly used material
- Airframe manufacturer and authority approval
- Economical

2.2 The Ideal Process

Is there any ideal process?

An optimized process would only require a minimum of energy, which would be necessary to neutralize the binding energy between the paint layers. It seems that this can only be carefully directed by chemical, biochemical or even biological processes. Presumed that the basic process requirements can be met, the optimized process would then consist of three steps (Fig.2.1). After application of an environment-friendly agent, a dwell time of about two hours would only be needed before it is finally rinsed off with water.

The process must be capable of stripping the topcoat down to a particular primer only. Just paint debris need to be disposed of, after the water is filtered. The new envisaged chemical agent has to be biodegradable.

In comparison to mechanical processes the technical complexity would be considerably reduced with almost no capital investment. Existing facilities could be used.

The development of agents for such an optimized process, requires a joint effort between manufacturers of paint and paint remover. In fact, today the development of integrated paint & stripper systems

needs attention. Only two years ago the situation was completely different. While manufacturers were continuously enhancing the performance of the paint, others were looking for more aggressive paint strippers. Furthermore, the development of alternative chemical processes, was virtually smothered by the world wide activity seeking to find a mechanical solution.

2.3 Mechanical Processes

What about mechanical processes?

Since the mid 80's there has been world wide activity in searching for mechanical methods, to serve as substitutes for the classical chemical strippers. Several techniques, including plastic media, wheat starch, or carbon dioxide blasting, have been under close investigation at LUFTHANSA's Engineering department. None of them however, could offer more potential, for a future large scale application and optimization, than the high pressure water jetting.

Nevertheless, it has to be remarked that environmental-friendly technologies are also meant to be optimized with regard to their specific energy consumption. Yet all mechanical technologies from high pressure water jetting to laser stripping consume a relatively large amount of energy and dissipation is considerable. Energy costs of today's alternatives are approximately 5 to 8 thousand marks (based on a 747 strip), depending on the particular technology. In general the processes are highly complex and capital is tied up by the technical expenditure.

2.4 LUFTHANSA Policy

What is the Lufthansa objective with regard to paint removal?

⇒ LUFTHANSA's demands the development of integrated systems of paint & stripper. Paint schemes must be formulated with regard to their particular stripping agent. This issue was addressed to the aircraft manufacturers and paint suppliers. This demand is part of the aircraft specification issued by LUFTHANSA.

⇒ A mechanical alternative is only considered as an interim solution, until new envisaged paint schemes are applied to aircraft skins.

⇒ LUFTHANSA considers AQUASTRIP to be the best interim technology to remove old paint schemes for the next decade, unless another chemical, biochemical, or biological solution is found.

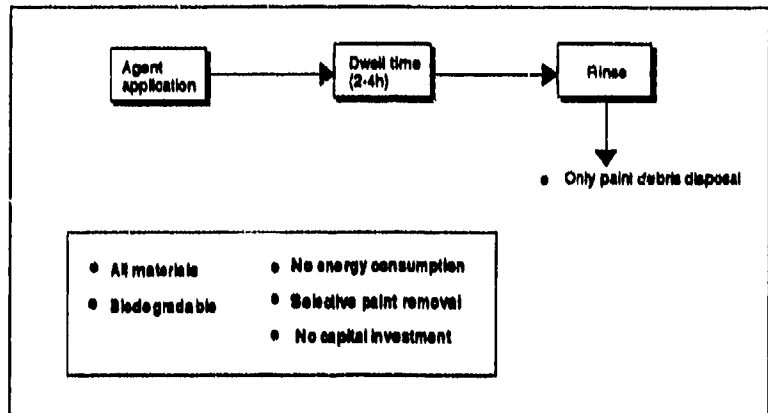


FIG. 2.1 Ideal Process

3. HIGH PRESSURE WATER TECHNOLOGY

3.1 General Process Advantages

Why high pressure water?

Liquid water offers an almost unlimited range of applications. If pressurized and channeled through a nozzle, the same water can be changed into an endless range of shapes, from droplets of different sizes to coherent jets, adaptable to the particular area of application, such as washing or cutting.

Tests conducted at LUFTHANSA, showed the high potential of a water jet also being utilized for an innovative paint removal technology on thin aluminium skins. Based on these trials, the decision was made, to design and equip the new paint hangar for high pressure water application.

The outstanding features are evident enough to enhance the development of high pressure water paint removal:

- natural medium
- 100% availability
- inexpensive
- easy to handle
- no storage problems
- experience in treatment/disposal of water
- high recycling rates
- dustless
- only paint debris disposal
- fast
- selective stripping feasible
- commercially available high pressure water technology
- relatively low capital investment

4. THE AQUASTRIP TECHNOLOGY

4.1 Process Assessment

Experiments were conducted as early as 1982, and systematic research was started in 1987. Several nozzle configurations were tested, angle of attack, stand off distances and rotation speeds were varied in order to establish a preliminary operation window.

In 1987, further experiments on aircraft components with commercially available equipment showed that the possibility of damaging the material was proportional to the water pressure, which was consequently reduced to a safe level. It was also discovered that conditioning of the paint layer with a harmless agent would ease and accelerate the paint removal process. It also gave better control of the process for selective paint layer removal. The performance of many different softeners were tested on a variety of paint schemes currently used on aircraft. The influence of the paint thickness and age has been studied. A formula for the necessary dwell time was derived from these tests.

4.2 Basic Process Definition

- The AQUASTRIP technology utilizes *high pressure water jets* to selectively remove paint from metal or composite aircraft structure.
- AQUASTRIP is defined as a *hybrid process*. It optionally utilizes chemical softening of the paint layer in a first step.

4.3 Physics of Aquastrip Paint Removal

How does the water jet work?

Water jets are directed onto the aircraft skin at an angle of 60° forcing themselves under the layer of paint and literally peeling it off.

Physical phenomena of the paint removal by high speed water jets have not yet been thoroughly investigated. Different mechanisms of paint removal were observed. When softener is applied to the top coat prior to AQUASTRIPPING, it is most likely that hydraulic peeling becomes responsible for paint removal. The water jet takes advantage of a weakened interface between primer and top coat. This is also true for many paint schemes even without having been conditioned.

Inhomogeneities in the surface, like scratches, or changes in material properties are the initiation point for paint layer removal.

Erosive paint removal can be explained by either liquid/droplet impact or cavitation impact. Under parameters currently employed, the erosive process is very slow. However, on the other hand it is advantageous with regard to substrate damage.

4.4 Operational Parameter

What is the operation window?

Structural
Engineering

AquaStrip
Process Parameter

Parameter	Metal	Composites
Tool type	shrouded disk 60 deg. angle rotating system	
Water pressure	max. 500 bar	max. 300 bar
Water outflow	38 ltr./min and head	
Jet velocity	approx. 320 m/s	
Rotation speed	2000-6500 RPM	
Nozzle size	1 mm	
Stand-off	30-150 mm	
Traverse rate	50 mm/s +/- 10 mm/s	
Water Temp.	18-24 degr. C (up to 80degr. C)	

Jet energy partially used for disk rotation (no external drive)

The basic water tool consists of two nozzles integrated in a rotating head. The head's rotation speed is 2000-6500 RPM. It is driven by an impulse from the water jets due to eccentric alignment of the nozzles.

The system operates at a maximum water pressure of 500 bar (7,250 psi). With a nozzle diameter of 1mm, the jet velocity is calculated to be 320 m/sec. The water outflow for one nozzle is around 20 ltr./min. Drinking water of 18-24° C is normally used. Hot water (80°C) application is in an experimental stage.

Typical *traversal speed* is 50 +/- 10 mm/sec.. Stand-off distance of the nozzle from the surface is 30 to 150 mm, depending on the tools used and the area of application. At 30 mm stand-off distance, a paint stripe of 100 mm is removed.

4.5 Applicability

Which paint systems can be effectively removed?

AQUASTRIP is designed and tested to remove polyurethane top coats currently used by airframe manufacturers. Removal of epoxy, acrylic or other paint schemes is feasible, but no extensive tests have been performed. AQUASTRIP has also been successfully tested for removal of thermal coatings on thrust reversers.

The removal of adhesive foil used for logos or, in future, riblet foil, ("Dolhin skin" designed for low friction drag and thus fuel savings) is easy, at low system pressures of around 200 bar.

4.6 The Softening Process

When and how are softeners used?

Extensive test series showed that softening is required in approximately 60% of all stripping jobs (Fig. 4.2), depending on the age and condition of the paint system. The softener dwell time has to be calculated for each individual paint scheme. A characteristic of the softening phase is the maximum allowed dwell time of 2-4 hours. It is then rinsed off with water prior to the high pressure water jetting.

Softeners qualified for the AQUASTRIP process had to be compatible with respect to environmental and health regulations. Two products (Turco 1270-5 and Brent LB2020) are currently qualified. They are based on biodegradable contents like Benzyl Alcohol.

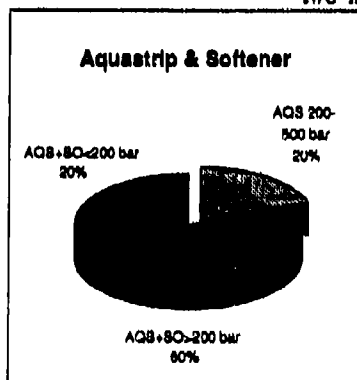


Fig. 4.2 Softener application

4.7 AQUASTRIP facilities and equipment

What does the hardware look like?

4.7.1 Facilities

Two AQUASTRIP facilities are currently in operation on the LUFTHANSA overhaul base.

- The AQUASTRIP-center
- The PAINT & STRIPPING HANGAR

The AQUASTRIP-center for aircraft components was opened in 1990. This facility is also equipped for hot water applications. The two boxes in the new paint and stripping hangar can accommodate a 747 and an A300 at the same time. Six ceiling mounted stagger cranes (telescopic-platforms) are operated in each hangar box designed to carry the AQUASTRIP manipulators.

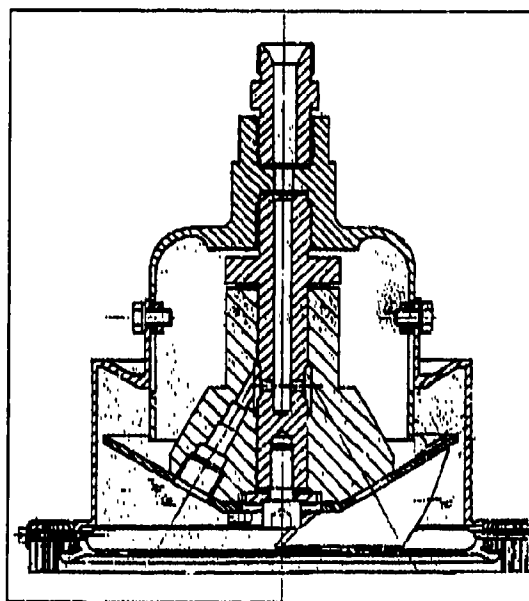


Fig. 4.5 Cross-section of the water tool

4.7.2 Equipment

The basic water tool consists of a rotating head with two nozzles, as described previously. A fan mounted onto the rotating head provides suction which substantially reduces the spray. The energy consumption results in a reduction of the rotation speed to approximately 3500 RPM. By shrouding the whole unit a noticeable noise reduction is achieved. This unit (Pat. 2.) is used for both the manipulator and the hand held tools (Fig.4.5).

Manipulators:

Six basic water tools are carried by each manipulator. The heads are staggered to ensure stripe free paint removal. The unit is mounted onto the telescopic platforms. The semi automatic control provides distance control and contour adaption. Ultrasonic and mechanical collision avoidance sensors prevent accidental damage to the airframe. The manipulator is designed and built by MBB /1/.

Manually operated tools:

For inaccessible areas, a single water tool is used. The tool is manually operated but counter- balanced for ease of handling. Different balancing systems were designed for ergonomic operation in different areas.

High pressure system:

Fresh or recycled water is pre-pressurized to 6 bar before eight piston pumps pressurize the water to 500 bar (7.250 psi) maximum. The equipment supplier is WOMA /2/.

Waste water management:

A special drainage system allows separation of rinsing water from the softening process, and the AQUASTRIP water. The water from the strip process is directly treated in a decanter/separator and stored for re-use. The water can approximately be recycled three times. Softener loaded water is treated in a central sewage treatment plant for biological degradation.

4.8 Process Performance

How long does it take to strip an aircraft?

The performance of the process is tabled in Fig. 4.5 for a single head and one manipulator for different tasks. It shows net values only. No preparation or positioning times are considered.

With a single head, a square meter of PU-top coat can be practically stripped within five minutes, which is equivalent to 12 m²/h (130 ft.²/h). One unit on a manipulator (6 single heads) is able to remove approximately 80 m² of top coat within one hour (860 ft.²/h), including preparation and positioning times. By using 4 Manipulators a 747 can therefore be easily stripped within a single 8 hour shift.

	Water Head		Traversal rate	
	38 lit./min.		50 (mm/sec.)	
For	Single head		Manipulator	
Width	100 mm		600 mm	
Time	3,3 min		0,6 min	
Water	126,7 lit		126,7 lit	
Area	18 m ²		108 m ²	
Water	2,3 m ³		13,7 m ³	
Area	1350 m ²		1350 m ²	
Time	78 h		12,5 h	
Water	171 m ³		171 m ³	
Area	480 m ²		480 m ²	
Time	25 h		4,2 h	
Water	57 m ³		57 m ³	

Fig. 4.5 Performance of the AQS process

4.9 Process Development

Can performance be enhanced?

Based on the experience gained up to now, several process optimization steps are feasible to enhance process efficiency.

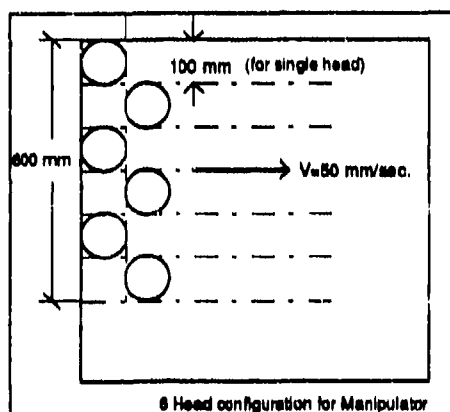
- Higher water temperatures have proved to be more effective. Water temperatures of 40-80° C enabled us to remove almost every paint system and scheme without using softener.
- Increased softener temperatures are also likely to improve performance, resulting in reduced dwell times.
- A re-design of the nozzle configuration is being initiated. It will focus on the reduction of cycling loads to obtain even more operational safety, and enhance the process performance.
- Higher system pressure and reduction of water volume may lead to complete redundancy of softeners. Yet, the primary concern in this development is the structural safe operation for semi-automatic and manual operation as performed today.

4.10 Health & Safety aspects

Are there any potential health hazards?

With regard to water as a media, there are no hazards at all. Concentration of heavy metal particles in the aerosole are very low, according to continuously performed measurements. Therefore, they are of no concern in regard to personnel health hazards.

In order to prevent accidental injuries by direct contact with the water jet, special security devices are installed to the manually operated tools.



5. AQUASTRIP RESEARCH PROGRAM

How did Lufthansa prove that AQS does not deteriorate the structure?

5.1 General

Even though high pressure water jetting has already been used in various applications, substantial additional efforts had to be invested in the process development in order to determine an adequate set of parameters, which enables us to remove paint layers from thin aluminium aircraft skins today. The purpose was to establish a process allowing non automated operation with a maximum of operational tolerances and a minimum risk of material deterioration.

In a *preliminary investigation stage* the work was focused on process efficiency, by variation of:

- nozzle configuration
- angle of attack
- pressure
- rotation
- softener performance & specification

5.2 Investigation Program

Which subjects were investigated?

In the second stage, in 1988, a *test and evaluation program* was defined with the assistance of the Boeing Company and the Cranfield Institute of Technology (UK). The objective was to prove that the range of defined working parameters ensure that both short, and long term integrity of the aircraft structure is maintained. Several independent institutions were involved in the research program.

The Boeing document D6-55564 and the IATA "Guidelines for evaluation of aircraft paint stripping materials and processes" were later derived from this initial investigation program.

The investigation program covered central structural aspects:

- Softener compatibility
- Material damage
- Fatigue life,
- Water penetration
- Bonded structures

All tests were initially performed on metallic structural parts. An enormous amount of time and money was invested into the process assessment to achieve the certification level of today and show that

all the new and strict requirements can be met. With the knowledge of the details and the depth of the research performed, it can be stated that no classical chemical process would have ever passed these tests.

5.3 Summary of Test Results

In the following, a short summary of the investigations and test results is given:

5.3.1 Softener compatibility

Only two softener products are qualified for the AQUASTRIP process (Turco 1270-S; Brent LB 2020). Since they do not contain any acid ingredients, they were found to be sound with regard to pitting or etching corrosion. They pass the sandwich corrosion test and do not induce hydrogen embrittlement. The weight loss in the immersion corrosion tests was below the limits. Degradation of elastomers was not detected.

5.3.2 Substrate damage

Theoretical work was initiated to find a correlation between the process parameters, the materials micro structure and the erosion mechanism.

Metallographic investigations (SEM, TEM) were performed on ALclad 2024 T3, ALclad 2024 T3 CAA, for different stand-off distances in traverse and stationary mode for different material thicknesses.

For the dynamic operation and the worst parameter combination, no significant damage to either clad or anodized layers was found even after a very high number of AQUASTRIP cycles. It was further experienced that damage is likely to occur in a stationary condition within a relatively short time frame of 5-10 seconds. It is assumed that in a first stage the droplet energy is partially dissipated by plastic deformation of the clad layer, which results in crack initiation within the anodized layer. In an advanced stage of the stationary condition, clad removal will be initiated, thus, the stationary mode must be avoided, especially on unpainted metal surfaces.

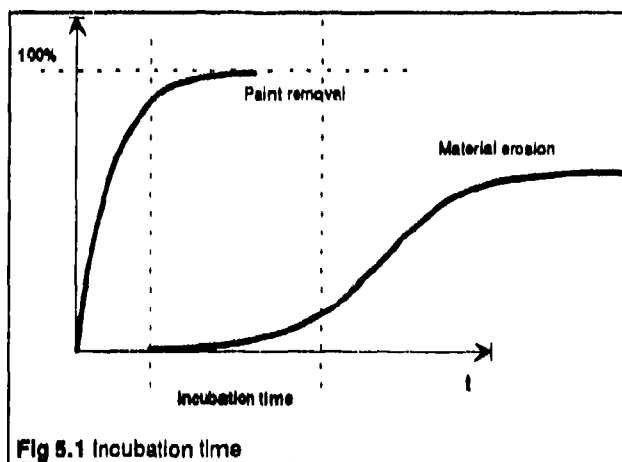


Fig 5.1 Incubation time

All this points to the presence of an incubation time, (Fig. 5.1) before erosion damage and thus material loss can occur. [1]

Residual stress introduced into the material is negligible. Arc height deflection of 10 μm is far below the acceptable

limits of 150 μm for all materials tested. Even for high cycling numbers and low stand-off distances, a value of 10 μm was never exceeded.

Cadmium plating will not be removed from fasteners.

5.3.3 Fatigue life

In 1989 holographic and strain gauge measurements were performed on a 727 fuselage during an AQUASTRIP trial. These measurements were compared to those of polishing and engine run up. Frequency and fatigue analysis of the vibration tests revealed that the induced fatigue life reduction is below critical levels for 100 mm stand off distance.

Tests were continued in 1991 and concentrated on local stress induction in the vicinity of the jet impact point at 30 mm stand-off distance. Relatively high strain levels of about 1600 $\mu\text{-strain}$ were measured, which were likely to alter the fatigue life of the material. It was found that strain increases almost linear with system pressure. Strain and stress values are almost constant between 30 and 50 mm and decrease with elevated stand off distances.

A parameter variation for sheet thicknesses, pressure and nozzle diameter provided a better understanding of the effects on the structural material.

In order to verify the impact of the surface anomalies and measured cycling loads on the fatigue life, a test program was defined by BOEING. Three batches of specimens were taken from a rebuilt fuselage section, after they were water jetted a maximum of 20 times in painted as well as unpainted condition. The specimens were cycled on a hydraulic testing machine and the cycle numbers compared to the life of the saved samples from the same batch. Despite differences in life which are evident from batch to batch, due to variation of material thickness, no influence of the stripping cycles could be verified (Fig. 5.2). Therefore, fatigue is of no concern for the set of process parameters defined.

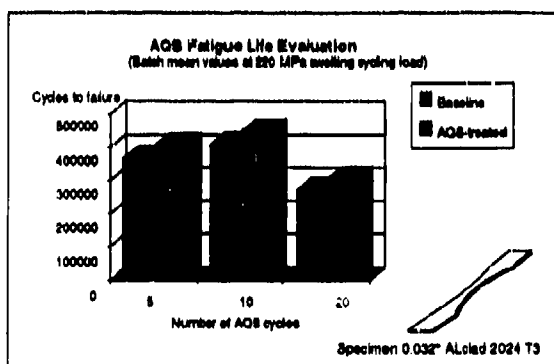


Fig. 5.2 Results from Fatigue Tests

The tendency of stripped samples to withstand more cycles seems to be evident, but has to be proven by a higher number of specimens. Whether a peening effect from imploding bubbles during cavitation or droplet impact is responsible [1], [2] has to be verified.

5.3.4 Water penetration

To show evidence of water intrusion in structural joints and rivet holes, a representative set of lap and butt joint configurations were AQUASTRIPPED and subsequently inspected by neutron radiography. A detailed analysis of numerous pictures was performed, indicating that water migration is likely to occur only into cavities which are directly accessible for the water jet. This can be the case for non-bonded, dry mounted or non faying surface sealed joints when edge sealer is removed due to AQUASTRIPPING, and loose rivets.

5.3.5 Bonded structures

Effects on bonded structural parts have been verified in a series of tests with different bonding systems. For both 125°C and 175°C cured systems no detrimental effects could be detected by either roller ball or drum peel test.

N-ray inspections showed that intact bonded or sealed surfaces are not effected and pre-defective areas were not found to be enlarged due to AQUASTRIP.

Additionally, the bonded sections of an Airbus 310 fuselage section used for demonstration purposes since 1989, have been continuously inspected visually and by *Fokker Bond Test*. Even after 45 stripping and repainting cycles, there is no evidence of debonding, corrosion or other defects.

5.3.6 Seals

The likelihood of seals to be effected by high speed water jets is high. If the jet is directed onto the sealer edge, it will possibly be removed.

5.3.7 Others

Other investigations with no or minor likelihood of structural impact have also been completed. Among them are the paint adhesion test, and health aspects like aerosol and heavy metal concentration, water recycling and treatment, masking and protection, media control quality check and ergonomics.

5.3.8 Composites

Investigations for composite structures are not completed, yet numerous tests have been performed. At this stage it seems that AQUASTRIP cannot generally be applied on composite components. Many parts like

rudders or radomes were successfully AQUASTRIPPED. Outstanding good and fast results like on 737 rudders were experienced without initially using softener, whereas other parts would not be strippable without damaging the matrix.

As a result of diverse tests, it was found that each individual composite part has to be tested, prior to AQUASTRIPPING. The system pressure is limited to 300 bar maximum.

The application of softeners, qualified for AQUASTRIP on composite parts, is of no concern according to tests already conducted at LUFTHANSA and by the suppliers.

5.3.9 Sandwich structures

Preliminary results do not indicate any deterioration of structural sandwich constructions, for both metal and composite material. The application will therefore be postponed, until final results are available.

6. PROCESS APPROVAL

Is the process approved?

6.1 Boeing Company

Based on the afore mentioned investigations, which were mutually defined by Boeing and LUFTHANSA, Boeing did not have any technical objection for application on components removed from the aircraft. This was confirmed by a "No technical objection" statement in 1990. This enabled us to strip monolithic sheet metal structures with a stand-off distance of 100mm.

The research program was recently completed for the operating parameters applicable in the large scale operation. The approval will be given very shortly, initially for metallic structural parts.

Since Boeing and LUFTHANSA's policy is to eliminate the slightest structural risk, with regard to the likelihood of water penetration, the application will be restricted. Structural joints which are not faying surface sealed or structurally hot-bonded, will be excluded or masked prior to AQUASTRIPPING.

6.2 Airbus Industries

Since 1990 Airbus Industries have been involved in the process qualification. The review of the test reports has almost been completed. Additional research had to be initiated to cover special Airbus requirements. Fatigue tests for notched specimen have to be performed according to the IATA Guidelines. The approval is also expected shortly.

6.3 Airworthiness Authorities

After preliminary research, the German Federal Aviation Authority (LBA) was involved 1990 in defining and approving a test and verification program. Approval was then given under consideration of restrictions from the airframe manufacturers. Recording and monitoring procedures were established for all active structural components which were AQUASTRIPPED.

The approval from other European authorities is envisaged, based on the OEM approval and ATLAS group agreements.

7. ECONOMICAL ASPECTS

What does it cost?

A valid cost comparison is very difficult to perform, because adequate and standardized data are not available. On the other hand, some aspects, for instance the necessity of dustless operation in a hangar which is subsequently used for re-painting, like in LUFTHANSA's case, cannot be quantified.

A comparison to classical chemical stripping is redundant and thus not performed, because any mechanical method is able to compete.

It was tried to compare AQUASTRIP, PMB and an

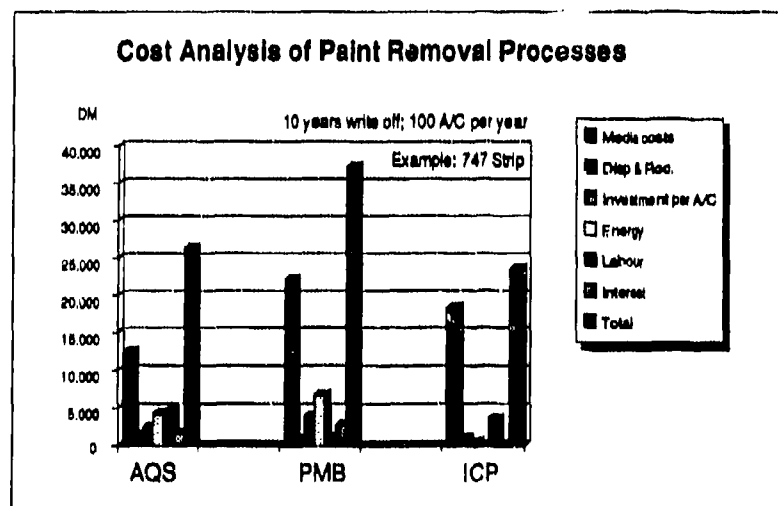


Fig. 7.1 Cost analysis

envisaged new chemical solution on an equal basis (Fig. 7.1 and Appendix). An amortization period of 10 years and an output of 100 aircraft per year is the basis for the calculation. Several aspects have not been taken into consideration because of their minor influence, like the maintenance costs of the equipment.

The most significant share of the total expenditure are the media and power costs.

The data analysis shows that stripping costs are approximately 18 DM/m² for AQUASTRIP and 25 DM/m² for PMB, whereas the innovative chemical process can do the stripping job for 15 DM/m².

8. PATENTS & TRADEMARKS

During the development of the process it became apparent that several aspects of the process were new and the potential for utilization in other fields was enormous. For this reason two international patents were registered in 1990, which cover the process and procedures as well as hardware developments (AQUASTRIP Water Tool).

For marketing purposes, the trademarks "AQUASTRIP + AQUASTRIPPING" were registered in 1990.

9. COOPERATIONS

A cooperation contract was already signed in the design & development stage between LUFTHANSA and the hardware manufacturers of the water tools and manipulators for development and marketing purposes.

Interest shown by many airlines in participating in the development and in utilizing AQUASTRIP in their own hangars has resulted in a cooperation contract between KLM and LUFTHANSA. The objective is a technology transfer and mutual research & development activities on the AQUASTRIP process.

10. CONCLUSIONS

AQUASTRIP is a viable solution to environmental, safety and health issues. It will be utilized for the next 5-10 years until new integrated paint systems are hopefully applied to most aircraft.

The extensive research program for the final process parameters and large scale operation, was recently completed. Airframe manufacturers and subsequently the authorities approval will follow shortly. AQUASTRIP has proved to be a structure-friendly and safe technology. A technology whose potential impact on airframe structures has been thoroughly investigated, more than ever done for classical chemical processes, will go into operation. Yet the development of

AQUASTRIP has not stagnated. Several possible enhancements are feasible.

In the last couple of years, other mechanical processes have also been developed to an operational stage and have proven their practicability. Today, having the choice, a decision for one or the other processes is not easy to make, and is strongly related to individual requirements.

11. REFERENCES

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[1] C. Verpoort, J.E. Field; "Verfahren zum Kaltverformen der Oberflächenzone eines Werkstückes und zum Einbringen von Druckeigenspannungen", Patent 88/061.

[2] Rieger, H.; "Über die Zerstörung von Metallen beim Aufprall schneller Wassertropfen", Z. f. Metallkunde 57(1966) Heft 9, S.693

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/2/ WOMA Apparatebau GmbH
Postfach 141820
D-4100 Duisburg 14

Patents:

1. Int. Patent PCT/EP90/01877; "Verfahren zur Entfernung von Anstrichen auf Oberflächen"

2. Patent 4039092; "Vorrichtung zur Entlackung von lackierten Oberflächen"

3. Trademarks "AQUASTRIP + AQUASTRIPPING"
Reg. No. 1169498 u. 499

Appendix

Cost Analysis of Paint Removal Processes

Provided Data			
747 Strip	1 Operating Unit		
250 kg Paint			
1500 m ² Surface			
Default dimensions			
	AQS	PMS	ICP
	Aquestrip	Plastic Media	Innovative Chem.
1. Working Media	Water	Plastic particles	Agent
Media Costs (DM/m ³)	5,0	5,3 DM/kg	12,0 DM/kg
Amount (m ³ /h)	13,7	2.000,0 kg/h	1,0 kg/m ²
Recycling rate	3,0	8,0	1,0
Performance (m ² /h)	108,0	90,0	
Time (hours)	13,9	18,7	4,0
Costs DM	317	22.083	18.000
2. Other Media	Softener	Air	Water
Media Costs (DM/m ³)	8,0 DM/kg	0,05	5,0
Amount (m ³ /h)	1,0 kg/m ²	50,0	50,0 m ³
Recycling rate	1,0	1,0	1,0
Costs DM	12.000	42	258
► Media Costs DM	12.317	22.125	18.258
3. Disposal & Recycling			
1. Working Media			
Disp. Costs (DM/m ³)		25,0	
Recyc. Costs (DM/m ³)	6,5		
Amount (m ³)	63,4	6,6	0
Recycling rate	3,0	8,0	
Costs DM	412	184	
2. Other Media			
Recyc. Costs (DM/m ³)	6,5		6,5
Amount (m ³)	51,5	0	51,5
Recycling rate	1,0		1,0
Paint debris disp. (DM)	625,0	625,0	625,0
Costs DM	960	625	960
► D&R Costs DM	1.372	789	960
4. Investment & Operational costs	100 (A/C per Yr.) Capacity Write off : 10,0 years		
Fix			
1. Working Tool	Manipulator	Manipulator	Auto spray
Costs/ unit (DM)	1.300.000	3.300.000	200.000
2. Conveyor system	Pump	Compressor	Pump
Costs/ unit (DM)	750.000	50.000	80.000
3. Cleaning systems	Decanter	Filter	Decanter
Costs/ unit (DM)	200.000	500.000	100.000
4. Other equipment	Hoses	Hoses	
Costs/ unit (DM)	100.000	10.000	0
Tot. Invest. DM	2.350.000	3.860.000	380.000
► Invest. per A/C (DM)	2.350	3.860	380
Variables			
1. Power			
Spec. Costs (DM/kVh)	0,20	0,20	0,20
Power input (kW)	1500	2000	50,00
► Op. Costs (DM)	4.187	6.667	40
2. Labour Costs	60 DM/h		
Main proc. (hours)	14	17	60
Lab. Costs (DM)	833	1.000	3.600
Other proc. (hours)	60	0	0
Lab. Costs (DM)	3.600	0	0
► Labour Costs (DM)	4.433	1.000	3.600
3. Capital return			
► Interest (DM) 7,00%	1.645	2.702	252
Strip Costs 747	DM	26.284	37.142
			23.459

PAINT REMOVAL AND SURFACE CLEANING USING ICE PARTICLES

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SUMMARY

Research into the possibility of using ice particles as a blast medium was first initiated at Defence Research Establishment Pacific (DREP) in an effort to develop a more environmentally acceptable paint removal method. A paint removal process was also required that could be used in areas where normal grit blasting could not be used due to the possibility of the residual blasting grit contaminating machinery and other equipment. As a result of this research a commercial ice blasting system was developed by RETECH. This system is now being used to remove paint from substrates that cannot be easily blasted by conventional techniques and also to clean soiled or contaminated surfaces.

The problems involved in the development of an ice blast system, and its components and their functions are described. Due to the complexity of paint removal using ice blasting, parameters such as air pressure, ice particle size and ice particle flow rate were studied and adjusted to suit the nature of the particular coating and substrate of interest.

The mechanism of paint removal by ice particles has also been investigated. A theoretical model has been developed to explain the different paint removal mechanisms such as erosion by abrasion and erosion by fracture as they relate to ice blasting.

Finally, the use of ice blasting to remove paint from a variety of substrates is presented as well as examples of surface cleaning and surface decontamination.

1. INTRODUCTION

1.1 History of Ice Blasting

Ice blasting as a process for paint removal was first studied at DREP in the late sixties and early seventies. Initial experiments showed that ice particles could be accelerated by high pressure air and could be effective in removing paint from coated surfaces. A more systematic study of the effects of ice particle size, ice temperature, rate of mass flow, standoff distance and air pressure by G.W. Vickers^{1,2} showed

that ice blasting could be used to remove a variety of different coatings from metal surfaces.

In 1984 DREP contracted with RETECH to investigate developing the concept of ice blasting. During a series of contracts with RETECH the effects of nozzle design, ice particle size, ice particle size distribution and ice particle temperature on the rate of coating removal were studied and the ice blasting process refined.³ In 1988, using Defence Industrial Research (DIR) funding, a commercial ice blasting system was developed by RETECH. Refinements since then have led to the current commercial ice blasting system.

1.2 Advantages of Ice Blasting

Ice blasting was conceived as a dust-free coating removal technique for confined spaces (tanks or void spaces) or areas where conventional blasting could not be used due either to safety considerations or the possibility of damage to equipment by the ingress of blast media (eg. bilge areas of ships). More recently ice blasting has developed into a coating removal and cleaning technique for substrates that could be damaged by conventional paint removal techniques such as paint strippers and grit blasting.

The advantages of using crystalline ice as a blasting media as compared to other abrasive media such as grit, alundum or plastic are as follows:

- 1) ice is not abrasive and masking of most delicate surfaces is not necessary,
- 2) no dust is produced by ice breakdown thereby reducing the environmental impact of coating removal,
- 3) ice melts to water which can be readily separated from the coating debris thus simplifying disposal,
- 4) ice is easily made on site from water and electricity, reducing dependence on media suppliers, and
- 5) ice particles do not damage machinery or other equipment if contamination occurs.

1.3 Mechanism of Coating Removal Using Ice Blasting

Conventional blast media such as sand, grit or aluminum rely on the abrasive quality of the blast media to erode the coating from the substrate. Ice is a non-abrasive blast media which fractures the coating rather than abrades.

How a coating is removed from a substrate depends upon the nature of the particles used (hard or soft, blunt or angular) and the nature of the coating (brittle or ductile, thick or thin).

Blunt particles have an elastic impact at low velocities, and an elastic-plastic impact as the velocity increases. Angular particles have an elastic-plastic impact. With hard or abrasive particles the elastic-plastic damage occurs primarily on the coating, while with soft or non-abrasive particles it occurs primarily on the particles - they disintegrate.

Coatings can be brittle or elastic. When subject to particle blasting, coatings generally behave as brittle materials. The erosion of coatings by soft or non-abrasive particles occurs through fracture or through plastic deformation or through abrasion when the velocity of the impact is too low to cause fracture. The erosion of coatings by hard and abrasive particles normally is the result of plastic deformation. Some newer coatings are chip resistant and thus quite elastic and difficult to remove by any method.

In abrasion, a particle impinges on the coating at an oblique angle. On impact, it creates a crater and a lip or rim of displaced material as shown in Figure 1. Further impacts remove the lip material and/or create large craters. As abrasion relies on brute force, it is non-discriminating and either some of the coating remains or some of the underlying substrate is removed or damaged (Figure 1).

Substrate erosion is not necessarily a negative effect. For example, it provides the surface profile necessary for good paint adhesion, especially for high build coatings on steel. Substrate erosion also removes chemically bound corrosion products prior to re-coating. However, in some other situations, substrate erosion or damage can lead to serious problems of structural integrity.

The fracture theory of coating removal is shown pictorially in Figures 2 and 3. On impact at normal velocities ice particles transfer energy to the coating producing conical cracks. At higher velocities, radial and lateral cracks are also formed. Loss of coating material from the volume element defined by the intersection of the various cracks produces "sombrosos" structures (Figure 2). Further ice particle impacts tend to further the extension of the fracture lines along the coating/substrate interface (Figure 3) instead of creating more "sombrosos". This is because crack propagation in this plane requires overcoming the adhesive

force (mechanical bonds, hydrogen bonds, or van der Waals forces) which is much lower than the cohesive force (covalent bonds, ionic bonds or cross-linking) existing in the coating material or the substrate. Similarly creating new cracks in the coating or substrate requires more energy than extending the cracks along the plane between the coating and the substrate.

Evidence of the fracture mechanism came from microscopic examination of an ice blasted surface and the observation that during ice blasting, coatings were removed in large pieces the size of the nozzle diameter, or larger, rather than by methodical abrasion of the coating. Microscopic examination of a coated surface after ice impact, but before complete coating removal, showed that the coating was covered with small cracks and in some small areas no coating remained (Figure 4). These observations led to the theory that ice particles remove coatings by way of a fracture mechanism rather than by abrasion. The theoretical considerations of ice blast phenomenon have been described in two previous reports.^{4,5}

1.4 Mechanism of cleaning using Ice Particles

As ice is non-abrasive, it is ideally suited for cleaning applications where surface contaminants are to be removed from substrates, particularly delicate and fragile ones.

Although ice particles are non-abrasive, they provide physical agitation on impact. This mechanical rubbing action is sufficient to remove most non-bonded foreign matter. On melting the water serves to flush the surface free of debris.

Ice particles have also been found to be superior in removing surface contaminants from surface cracks and voids. This is likely attributable to the force developed by the physical deformation of the ice particles on impact.

2. ICE BLASTING APPARATUS

A schematic of the ice blasting equipment, consisting of an air conditioning module, ice making module and an ice conditioning module is shown in Figure 5.

Air from a compressor fitted with an aftercooler is diverted to two streams: about 15% of the air is dried and cooled down to -20 °C and the remaining is utilized unimproved. A single ice maker supplies ice at 90-115 kg/h; if more ice is required then several ice makers can be utilized. The ice is sized according to application. The size distribution is particularly dependent on the coating/substrate combination to be stripped. A precision metering fluidizer controls the ice particle flow rate. The instantaneous and continuous production, sizing, metering and fluidizing of the ice particles are constantly monitored and optimized by the ice

management system to prevent ice packing, clogging and interrupted flow. The fluidized ice is delivered through an insulated transport hose to the blast nozzle which can be up to 80 m away. High pressure air is injected at the nozzle at pressures up to 200 psi.

Accelerating the ice particles at the nozzle reduces the volume of high quality air, (refrigerated and dried) required for ice blasting. This reduces the overall energy required for ice blasting drastically. The high pressure air and the ice particles are only in contact for a short period of time and little ice particle degradation has been observed. A picture of an operating ice blasting system is shown in Figure 6.

3. EXAMPLES OF COATINGS REMOVAL BY ICE BLASTING

The ice blasting equipment was operated in two modes, low pressure and high pressure. The blast parameters used in the following examples are shown in Table 1.

3.1 Coating Removal From Graphite Epoxy Composites

A graphite epoxy panel was coated with the standard Canadian Air Force coating system, 25 μm of a strontium epoxy primer and 50 μm of a polyurethane topcoat. The coating was allowed to cure at 20 °C for one week. This coating was readily removed from the substrate at both high and low pressures with no visual damage to the substrate (Figure 7). Coating removal rates of between 225 cm^2/min and 450 cm^2/min were recorded. A scanning electron microscope (SEM) examination of the substrate after blasting also revealed that there were no broken or exposed graphite fibres and the top layer of resin was still intact. The sharp edges of the paint are indicative of a brittle fracture in the paint.

3.2 Coating Removal From Melamine

A formica melamine panel which is used as a joiner bulkhead in the interior of CP ships was coated with 50 μm of a marine alkyd coating. The alkyd coating was easily removed by ice blasting under both high and low pressure blasting conditions. A 15 cm square of the coating was removed in 4 minutes at low pressure and in 1.5 minutes at high pressure. There was no visual evidence of any damage to the formica melamine substrate (Figure 8). It was not possible to blast the formica melamine surface with conventional blast media such as sand or grit because these grits are too hard and will severely damage the formica melamine surface.

Due to the non-abrasiveness of the ice particles in the ice blasting operation the panel was blasted within 1.2 m of several parked cars. There was no damage to the vehicles and only a slight mist of water was evident on the vehicles

after ice blasting. The only protective gear required for the protection of the operator were ear protectors, goggles and water proof clothing.

3.3 Cleaning Of An Aircraft Polyurethane Topcoat

The aircraft epoxy/polyurethane coating system was also applied to an aluminum panel. The coating system was cured for one week at 20 °C and for one week at 65 °C. The coating was then soiled with a mixture of hydraulic fluid and carbon black which was cured in an oven at 75 °C for one hour. The excess soil was removed with a rag leaving a stained surface (Figure 9). The stains were easily removed using low pressure blasting with no visual damage to the coating surface (Figure 10).

3.4 Removal of Topcoat Only in a Multi-Coat System

Ice blasting can be controlled so that only the top coating in a multi-coat system is removed.

In some cases the polyurethane topcoat in an aircraft coating system can be removed from the epoxy primer. The nature of the substrate and the type of polyurethane and epoxy coatings affects not only the rate of coating removal but also whether only one or both coatings are removed.

A marine alkyd topcoat was readily removed from a steel primed with an inorganic zinc primer and a vinyl tiecoat. There was no damage to the underlying coatings. At higher pressures all three coatings were removed but at a much reduced cleaning rate as compared to removal of the alkyd topcoat only.

An acrylic coating (aerosol can) was applied to a fully cured high gloss polyurethane vehicle coating. The acrylic coating was successfully removed using ice blasting and no damage to the polyurethane coating was observed. This type of paint removal is similar to that required for removal of graffiti from vehicles or decals or other markings from aircraft.

A cuprous oxide anti-fouling vinyl coating was slowly removed from an aluminum vinyl anti-corrosive primer. The slow rate of removal resulted from the coating being removed by abrasion rather than by fracture. The selective removal of coating containing toxic or hazardous materials such as anti-fouling coatings or primers containing chromates can be accomplished by ice blasting.

The processing of the blast residue from ice blasting (ie. water and paint particles) is much easier than processing the blast residue after conventional blasting with media such as sand, grit, or aluminum. There is also a reduced volume of residue with ice blasting, and the nature of the residue (water and paint particles vs. grit and paint particles) makes separation of the paint particles much easier.

3.5 Ice Blasting Problem Areas

There were two areas investigated in which coating removal by ice blasting was difficult and incomplete.

An aluminum panel was grit blasted to a 50-75 μm profile prior to the application of the coating system. The blasted panel was then coated with wash primer, (8 μm), a zinc chromate alkyd primer (25 μm) and a marine alkyd topcoat (50 μm). The topcoat was easily removed from the primer and broke away in a brittle fashion but the primer was difficult to remove from the substrate due to the rough profile created during grit blasting. The primer remained in the valleys of the blast profile after ice blasting.

Similarly a steel panel, that had been blast cleaned to SSPC SP 6, Commercial Blast Clean, was coated with two coats of a high build epoxy (325 μm). This coating was exceedingly difficult to remove with ice blasting because the removal mechanism was abrasion rather than brittle fracture. Complete coating removal was not possible as some coating remained in the anchor pattern after ice blasting.

4. EXAMPLES OF CLEANING APPLICATIONS OF ICE BLASTING

4.1 Cleaning of Engine Components

Compressor blades, 7th stage, and turbine blades, 1st stage, from a JT9D engine from a commercial airliner were cleaned using ice blasting. All of the corrosion products and combustion products (Figure 11) were readily removed by ice blasting, thus increasing the efficiency of the engine. There was no damage to the underlying coating during the ice blasting process.

4.2 Cleaning of Molds

Molds and equipment used in the manufacture of automotive parts, aircraft composite components and automobile tires can be difficult to clean. The removal of any residual resin or rubber is critical to the optimum use of the mold or equipment, and in quality control in the production of items. Ice blasting has been proven effective in cleaning molds in tire manufacturing without damage to the mold. The ice blasting process can be easily integrated into existing manufacturing lines because of its simple operating requirements in terms of debris containment and waste disposal.

4.3 Radioactive Decontamination

Ice Blasting has been the subject of an extensive test by a major laboratory for radioactive decontamination.⁶ It has

also been used in commercial nuclear power facilities for decontamination purposes, including decontamination of reactor head areas. Water spray from melting ice serves to encapsulate airborne particles to prevent cross contamination during decontamination. About 40 litres per hour of ice blasting residue and water containing radioactive isotopes were produced which could be readily processed at the existing plant facility.

Conventional media blasting of areas requiring radioactive decontamination generates additional solid waste requiring disposal. High pressure water blast cleaning generates too much water requiring processing prior to discharge. Ice blasting is superior to high pressure water cleaning due to the mechanical scrubbing ability of the ice particles.⁶

4.4 Cleaning of Food Processing Equipment

Commercial food processing equipment containing grease, baked on grease or oil, burned sugar or food etc., has been effectively cleaned by ice blasting. Microbial tests of ice blasted surfaces have confirmed essential sterilization.

4.5 Other Uses of Ice Blasting

Vehicles used to clean up toxic materials or chemical spills may become contaminated with the toxic material during the cleanup process. Ice blasting has been used to decontaminate a vehicle prior to removal of the toxic material from the spill site. The vehicle was ice blasted while on top of a plastic sheet. The plastic sheet was used to contain and collect the ice blast residue. The collected residue of water and toxic chemical was then removed to a disposal site.

5. CONCLUSIONS

Ice blasting has been shown to have several advantages over conventional blasting processes. The amount of blast media used is small (~100 kg/h or 100 litres of water), and clean up and media contamination are either greatly reduced or eliminated. There is no need to store large volumes of contaminated media when removing toxic materials or hazardous coatings. The water can usually be separated from the coating quite readily and the water remaining can be further processed if required by reverse osmosis to reduce the volume of hazardous waste.

Ice is much softer and less abrasive than conventional media, and ice blasting can be used to remove paint from surfaces that would not tolerate conventional blasting media and processes. Ice blasting can also be used with little risk of damage or contamination of adjacent structures or equipment, due to the non-abrasiveness of the ice particles. For this

same reason minimal safety equipment is required for personnel.

Ice blasting has been developed as a commercial process and has been used successfully to remove graffiti from polyurethane coating systems, to remove aircraft coatings from graphite epoxy composite structures and to clean soiled aircraft coating. Ice blasting has also been successfully used to clean corrosion and combustion products from gas turbine blades without damaging the underlying ceramic or metallized coating. More recently ice blasting has been used to clean tire and composite molds used in manufacturing, and has been used to clean food processing equipment.

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TABLE 1 -- BLASTING PARAMETERS

Blast Parameters	Low Pressure Ice Blaster	High Pressure Ice Blaster
Input Air Pressure	80 psi	185 psi
Blast Air Pressure	80 psi	185 psi
Blast Air Temperature	25 °C	25 °C
Blast Air Volume	145 CFM	180 CFM
Ice Particle Size	3/16" - 1/4"	5/32"
Ice Particle Feed Rate	150 LB/HR	150 LB/HR
Standoff Distance	10-15 cm	7-12 cm
Angle of Blasting	75-90°	~90°

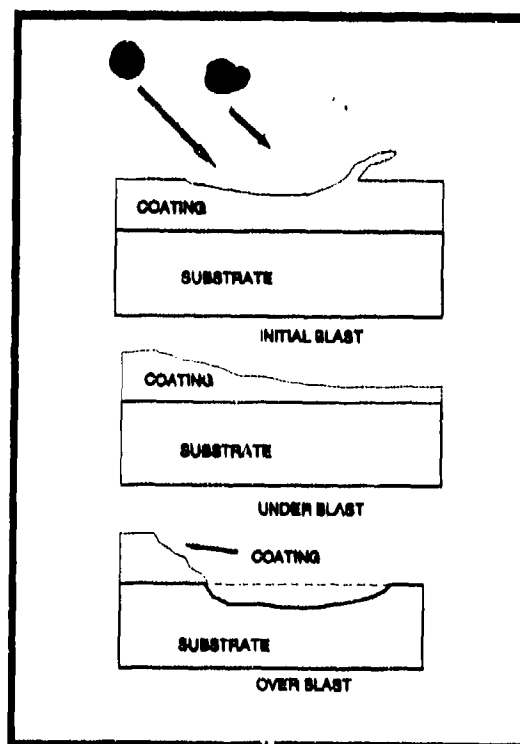


Figure 1 - Coating Removal By Abrasion.

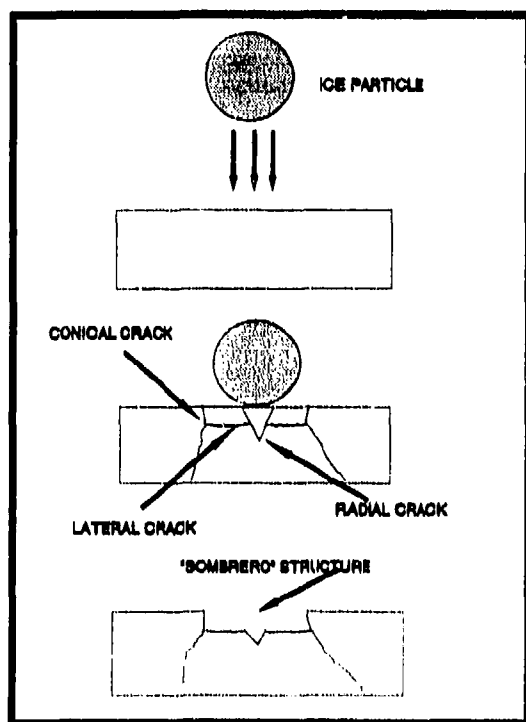


Figure 2 -- Crack Formation and Erosion by Fracture.

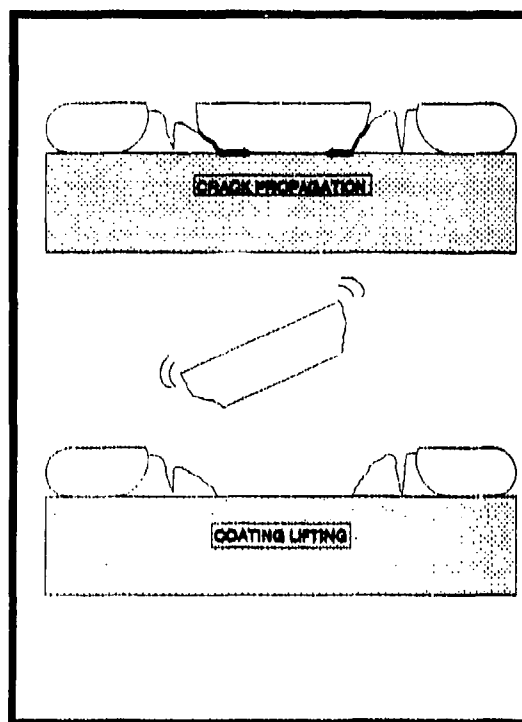


Figure 3 -- Crack Propagation and Coating Lifting.

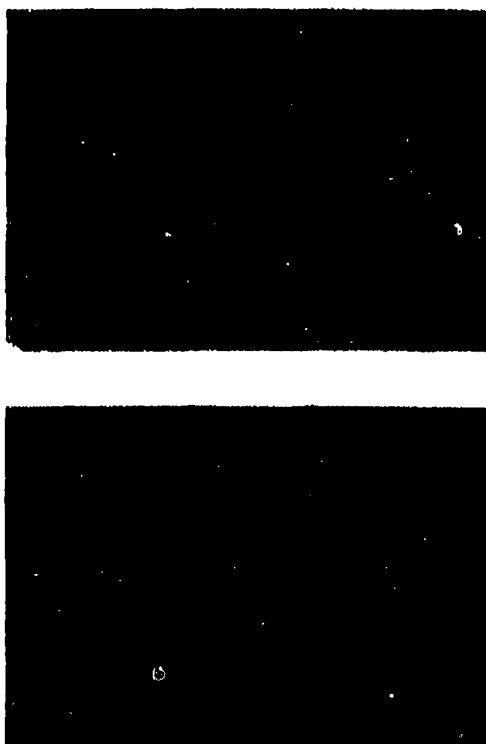


Figure 4 -- Surface Cracks Due to Ice Particle Impact.

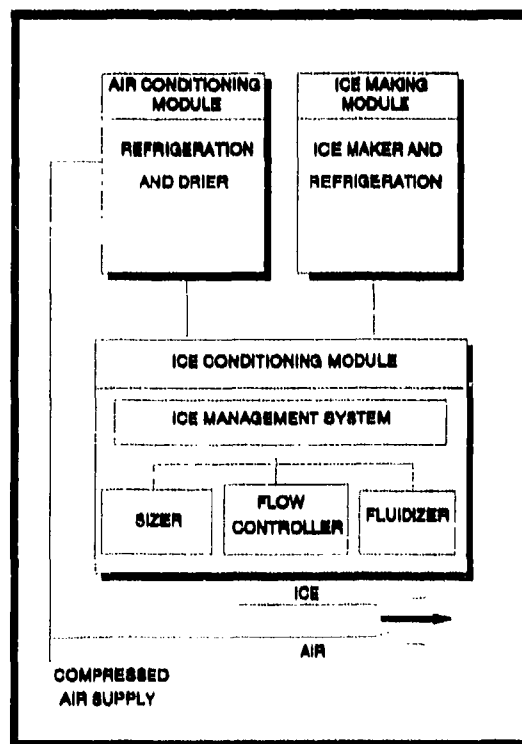


Figure 5 -- Schematic of Ice Blasting Equipment.

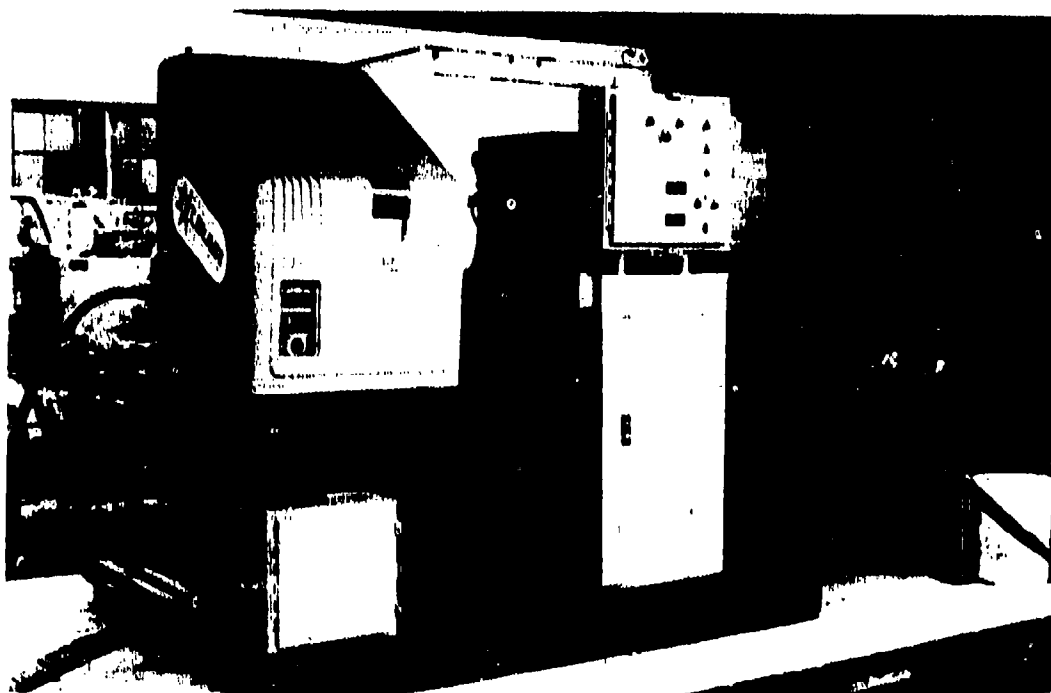


Figure 6 -- Ice Blasting Equipment

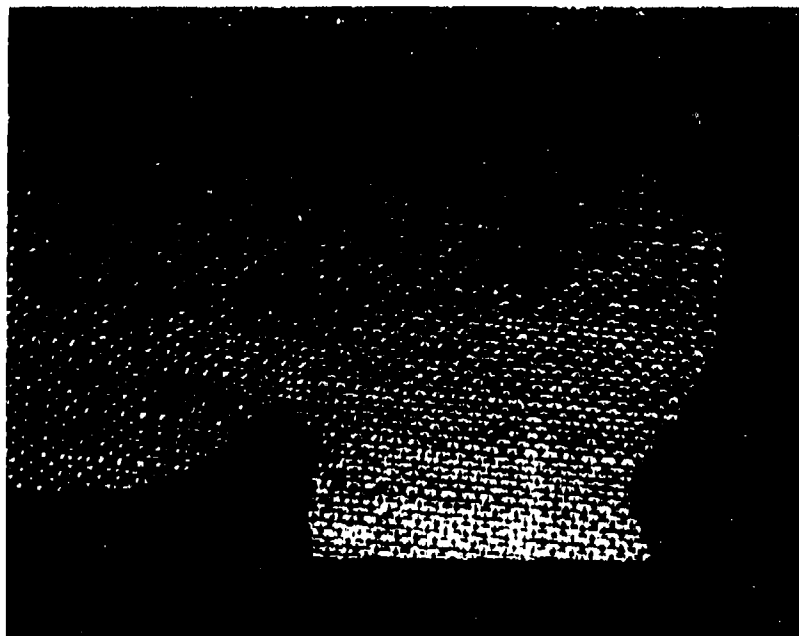


Figure 7 -- Aircraft Coating System Removed From Graphite Epoxy Composite Surface.



Figure 8 -- Alkyd Coating Removal From Melamine Panel.

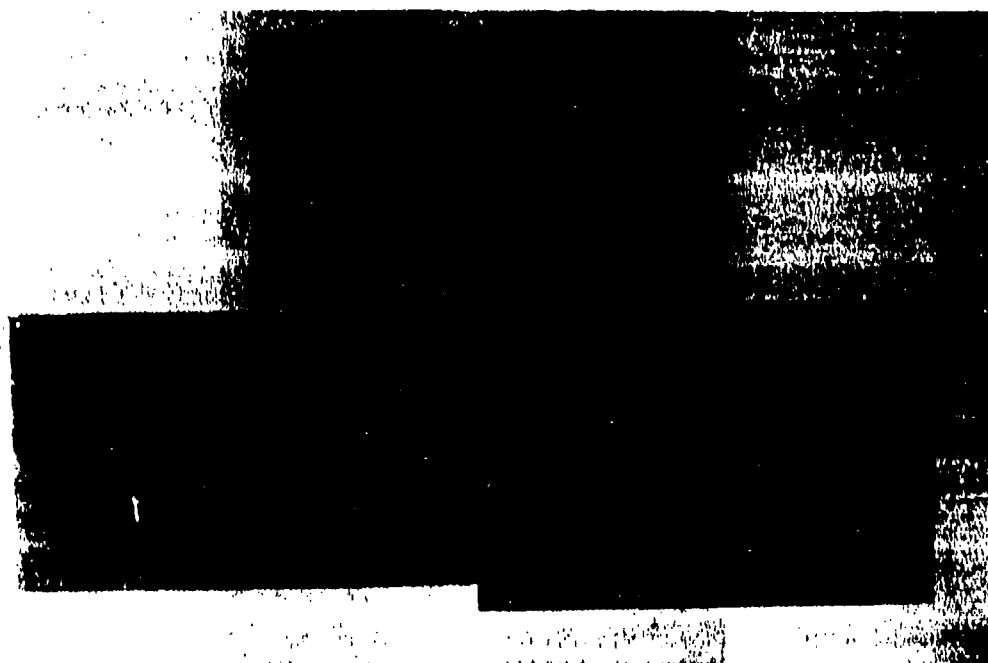


Figure 9 -- Soiled Aircraft Coating System Before Ice Blasting.

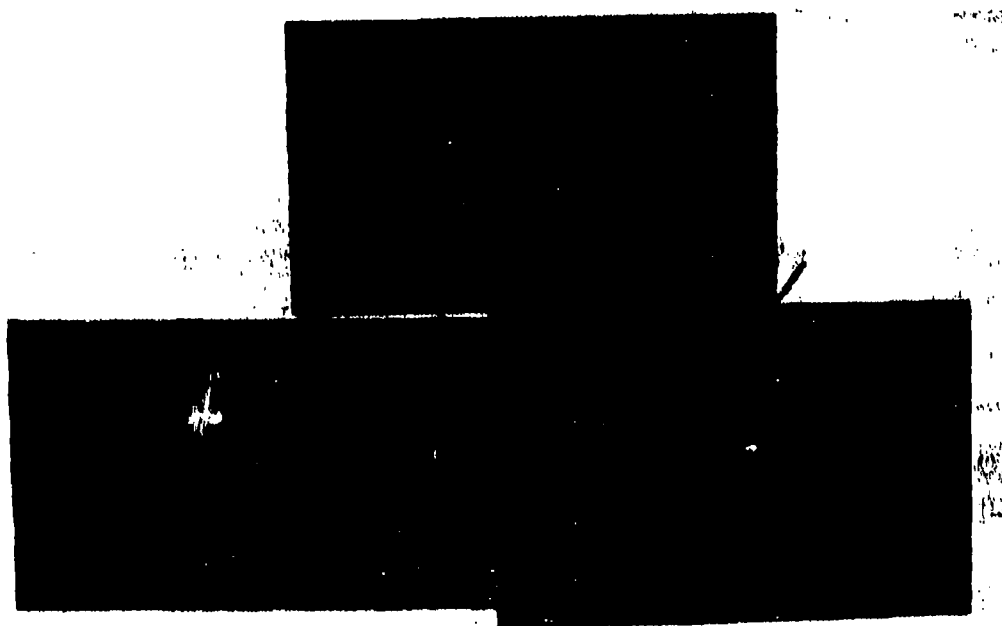
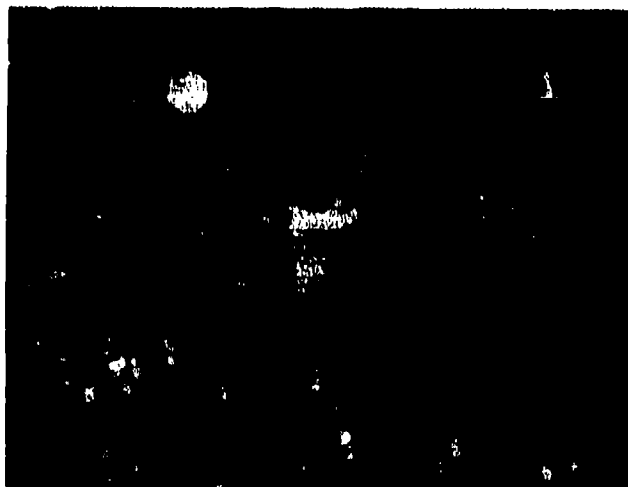


Figure 10 -- Soiled Aircraft Coating System After Ice Blasting.



JT9D Engine
Compressor Blade, 7th Stage
Top: before Bottom: after Ice Blast

Courtesy Japan Airlines



7A Type
Turbine Blades, 1st stage
Right: before Left: after ice blast

Courtesy Japan Airlines

Figure 11 -- Engine Components Before and After Cleaning With Ice Blasting.

Paint Removal Using Wheat Starch Blast Media

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SUMMARY

A review of the Wheat Starch Blasting technology is presented. Laboratory evaluations covering Almen Arc testing on bare 2024-T3 aluminum and magnesium, as well as crack detection on 7075-T6 bare aluminum, are discussed. Comparisons with Type V plastic media show lower residual stresses are achieved on aluminum and magnesium with wheat starch media. Dry blasting effects on the detection of cracks confirms better crack visibility with wheat starch media versus Type V or Type II plastic media. Testing of wheat starch media in several composite test programs, including fiberglass, Kevlar, and graphite-epoxy composites, showed no fiber damage. Process developments and production experience at the first U.S. aircraft stripping facility are also reviewed. Corporate and regional aircraft are being stripped in this three nozzle dry blast hanger.

1. INTRODUCTION

Introduced to the aerospace industry in early 1990, Starch Media Blasting is emerging as one of the best paint removal technologies available to replace chemical strippers. Manufactured by ADM/Ogilvie under the trade name Envirostrip, this innovative and environmentally-friendly product is used to strip a wide variety of aerospace coatings from airframe and aircraft components. Hailed as the dry stripping media of the future because of its gentle nature on aluminum alloys and composites, wheat starch media has won acclaim in test programs performed by Boeing Commercial Airplane Co., Beech Aircraft Corp., Northrop Corp., and military forces.

Starch Blast Media, as the name implies, is engineered from wheat starch. The media is non-toxic, biodegradable, and made from a renewable resource. A patented multi-step process takes pure wheat starch, a very fine powder, and transforms it into crystalline-like abrasive particles that look very similar to plastic abrasive media. Wheat starch media is used in the same conventional dry stripping systems designed for plastic media.

Although dry stripping has proven its merits in a production environment, many commercial operations have backed away from the plastic media blasting process because of its aggressive nature on aluminum. Wheat starch media overcomes this negative by delivering a more acceptable surface finish, most noticeably on clad aluminum alloys.

Wheat starch media is best known for its gentle nature on delicate substrates; the finish left on aircraft materials surpasses other dry stripping processes. Starch blasting leaves a smooth finish on aluminum, bare or clad, and can strip 2024-T3 aluminum skins as thin as 0.016" (0.41 mm) without deformation. For example, flight controls with unsupported bare aluminum, 0.016" (0.41 mm) and 0.020" (0.51 mm) thick, are stripped at 25 psi nozzle pressure without any deformation of the metal surface. Investigations have also proven that the finish on 2024-T3 clad aluminum is smooth enough to allow the aluminum to be polished to a mirror finish after dry stripping.

Wheat starch media also has the proven ability to strip composite materials, including graphite, fiberglass, and aramid (Kevlar) systems. Many composite stripping applications, both commercial and military, are underway. Coatings are stripped from composite structures with less risk of substrate damage than any other alternative being developed today. Several companies, including large defense contractors and commercial airlines, are finding that wheat starch media can remove coatings efficiently, and save enormous time over current techniques such as hand sanding.

Commercial and military testing has shown that wheat starch media removes a wide variety of coatings, from common polyurethane/epoxy paint systems to more sophisticated systems such as rain erosion resistant coatings found on radomes, and radar absorbing materials used on stealth aircraft. Coating removal applications also include removal of bonding adhesive flash from metal-to-metal bonded parts (while leaving the metal bond primer intact), removal of vinyl coatings (Tedlar) from aircraft interior panels,

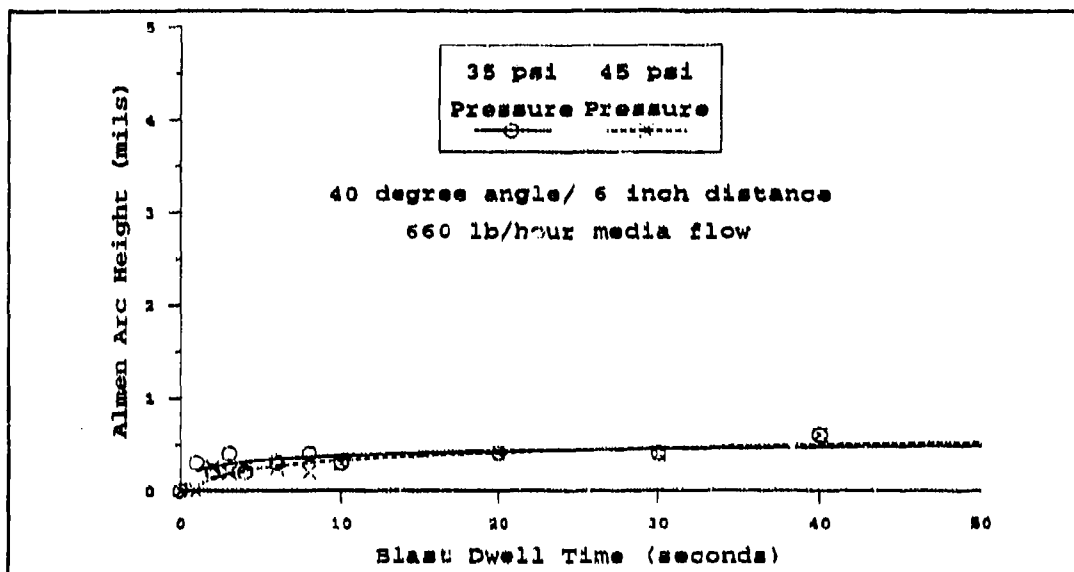


Figure 1. Saturation Response of Wheat Starch Media for 2024-T3 0.032" Aluminum.

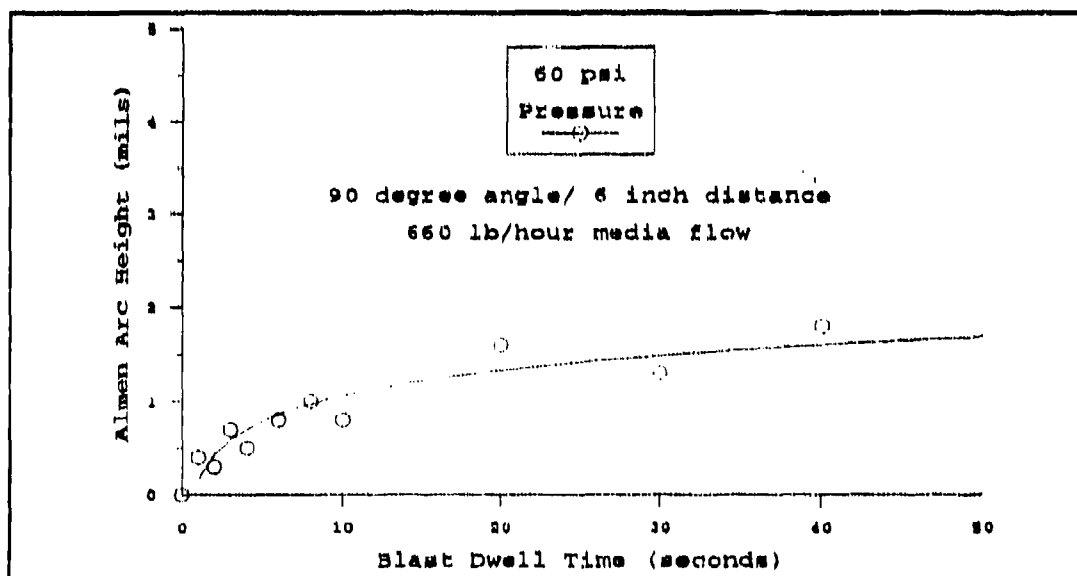


Figure 2. Saturation Response of Wheat Starch Media for 2024-T3 0.032" Aluminum.

and removal of sealants from components or fuel cells. Some recent applications involve paint removal from cadmium plated parts where the cadmium must be left in place. The list of different applications will continue to grow.

2. PROCESS LABORATORY DATA

Almen Arc Data for Bare Aluminum

The first investigation of residual stresses imparted by wheat starch media was performed

by Battelle¹ in 1991. This study tested the response of 2024-T3 bare aluminum alloy using 0.032-inch-thick (0.81 mm) Almen strip specimens 0.75 x 3.00 inches (19.0 x 76.2 mm) in dimension. An Empire blast cabinet was used with a 3/8-inch-diameter (9.5 mm) nozzle.

Saturation curves with virgin 12/30 size media were developed at 35, 45, and 60 psi nozzle pressure. Figures 1 and 2 present the saturation curves plotted with arc height as a function of blast dwell time. These pressures were at the

Table 1. Painted Almen Strip Arc Heights on 2024-T3 Aluminum for Wheat Starch Media.

Blast Process Parameters (pressure, media flow, stand-off)	Angle (degrees)	Mean Arc Height (mils)
50 psi, 660 lb/min MFR, 12" distance	70	0.64/0.38 (recycled media)
60 psi, 480 lb/min MFR, 6" distance	40	1.25/1.94 (recycled media)
60 psi, 480 lb/min MFR, 6" distance	90	2.36/1.66 (recycled media)
60 psi, 480 lb/min MFR, 6" distance	90	3.30/3.91 (new media)

extreme since most coating removal applications with starch media are conducted at pressures less than 35 psi. Ten data points, as measured by arc height, were generated at preselected time intervals. Several sets of blast parameters (varying angle and distance) were investigated. Figure 2 shows that even at very extreme conditions, arc height values did not exceed 0.002 inch.

Almen Arc Data for Painted Aluminum

Painted Almen strips were also tested in the 1991 Battelle study. All Almen test specimens (2024-T3 bare aluminum) painted for starch media blasting were prepared and painted to U.S. Air Force standards. Almen strip data were developed after four blast cycles; one actual strip cycle followed by three simulated strip cycles were performed. Simulated strip cycles reiterate the first strip cycle at similar process parameters and dwell times. Almen strips were not repainted between the initial and subsequent strip cycles.

In this test, recycled wheat starch media (four times) was evaluated alongside new media. Almen strip data are presented in Table 1 as the mean of five Almen specimens per set of process parameters. The greatest Almen arc height values were observed at parameters that are very aggressive (e.g. 60 psi), well beyond typical process conditions (e.g. 25-30 psi). This data showed that blasting with new starch media generally produced larger arc height values than recycled starch media.

The arc height data presented in the Battelle study (bare and painted Almen specimens) were very comparable to data observed with Type I plastic abrasives (polyester resin)².

Almen Arc Data Comparison with Type V

A recent study conducted by the Defence Research Establishment Pacific (DREP) of the Canadian Forces developed Almen arc height data on 2024-T3 bare aluminum and magnesium for wheat starch media and Type V plastic media. This testing was conducted with a Pauli & Griffin PRAM 31 blast cabinet using a 3/8" nozzle. An automated screw-feed valve was used to give

accurate control of media flow rates. Blast parameters were held constant by using a fixed nozzle and moving the Almen specimens under the blast stream.

Wheat starch media (12/30 mesh), recycled several times, was tested and compared to Type V Acrylic plastic media (30/40 mesh).

Standard 2024-T3 bare aluminum Almen strips 0.032-inch thick, 0.75 x 3.00 inches in dimension were used. Figures 3 and 4 present logarithmic plots of the saturation response of aluminum to both wheat starch media and Type V plastic media. Process conditions of 30 psi pressure, 12-inch standoff, 480 lb/hour media flow, and varying angles were tested.

Both media types approached saturation level, where arc height increases are minimal, after 2 minutes of blasting. The arc heights recorded with wheat starch were lower than Type V media under identical conditions. Most noticeable is the difference in the rate of change in arc height. With wheat starch media, the increase in arc height as a function of dwell time is more gradual. Type V arc height values increase quickly within the first 30 seconds of blasting. Note that a dwell time of 1 second corresponds to an approximate strip rate of 1 ft²/minute. Correspondingly, the residual stresses measured here within the first 10-15 seconds would generally exceed dry strip process effects encountered over the life of an aircraft.

To minimize the residual stress when stripping aluminum alloy, preferred parameters with wheat starch for a 3/8-inch nozzle are pressures of 25-30 psi, a stand-off distance of 8-12 inches, a media flow of 480 lb/hr, and an impingement angle of 45°-70°. These parameters provide the optimum wheat starch media strip rates for coating removal from aluminum alloys. The DREP study also generated Almen arc data for magnesium alloy, comparing the effects of wheat starch and Type V medias. Bare magnesium Almen specimens measuring 0.75 x 3.00 inches with a thickness of 0.042-inch (1.07 mm) were used. Even with thicker specimens, substantially higher arc height values were recorded for magnesium versus the aluminum alloy. Figures

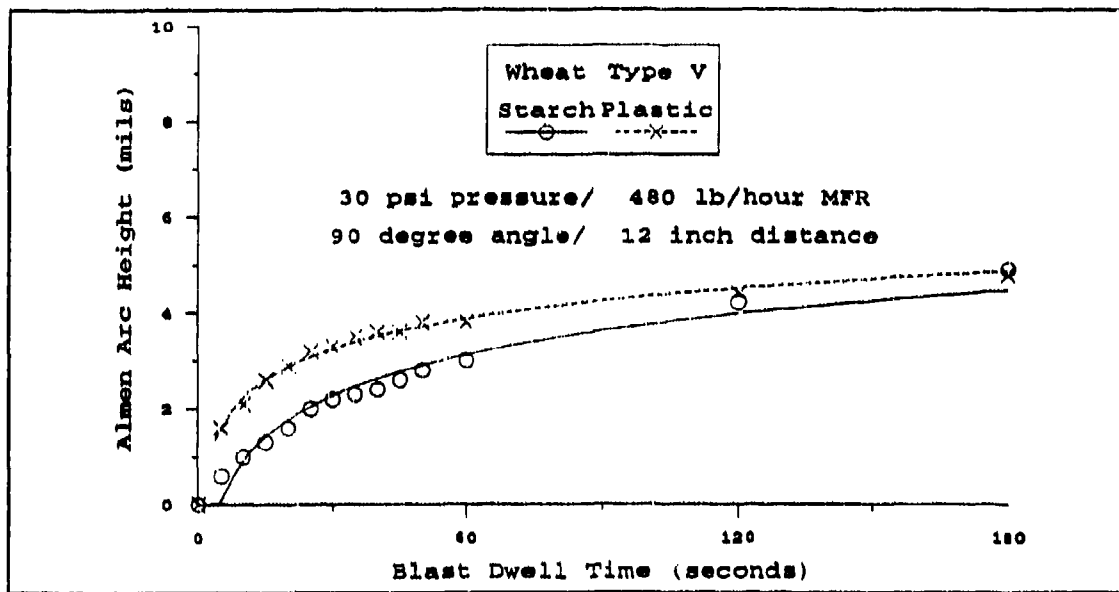


Figure 3. Saturation Response of Wheat Starch and Type V 2024-T3 0.032" Aluminum.

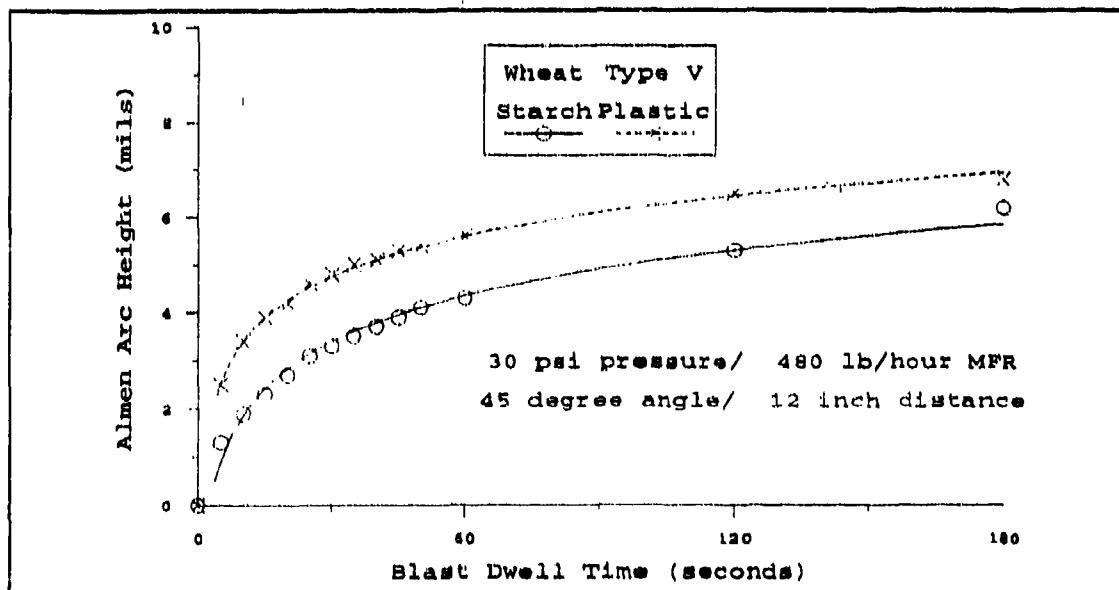


Figure 4. Saturation Response of Wheat Starch and Type V 2024-T3 0.032" Aluminum.

5 and 6 compare the effects of wheat starch and Type V medias. With Type V media, arc height values greater than 0.015-inch were recorded within the first ten seconds of blasting. Although arc heights for Type V media improved at a 45° angle, the warpage in the magnesium specimens was excessive. This data suggests that Type V plastic media is too aggressive for the softer magnesium alloy.

Residual stresses, as measured by Almen arc testing, show that wheat starch media imparts

lower stress levels to aluminum and magnesium.

Beech Aircraft Corp. in Wichita, Kansas has experience with stripping thin magnesium skins using wheat starch. Improperly prepared 0.025" magnesium skins must sometimes be stripped of MIL-P-23377 primer. Wheat starch media removes this primer without warping the magnesium, leaving the Dow coating treatment intact. The porous magnesium can retain some starch in the pores, which interferes with Dow #7 reprocessing. Abrading with Scotchbrite

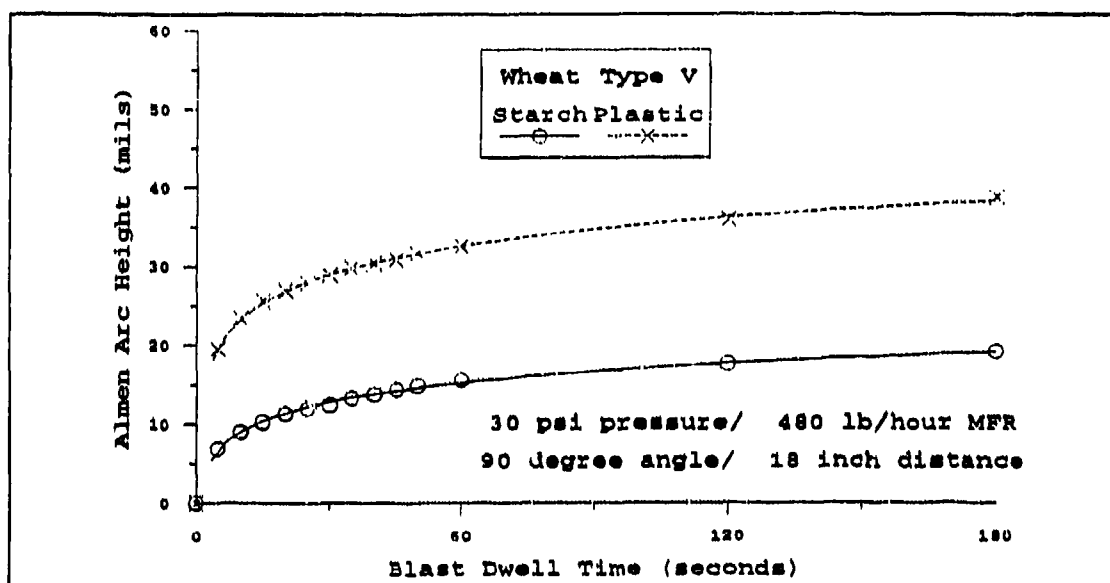


Figure 5. Saturation Response of Wheat Starch and Type V Media for 0.042" Magnesium.

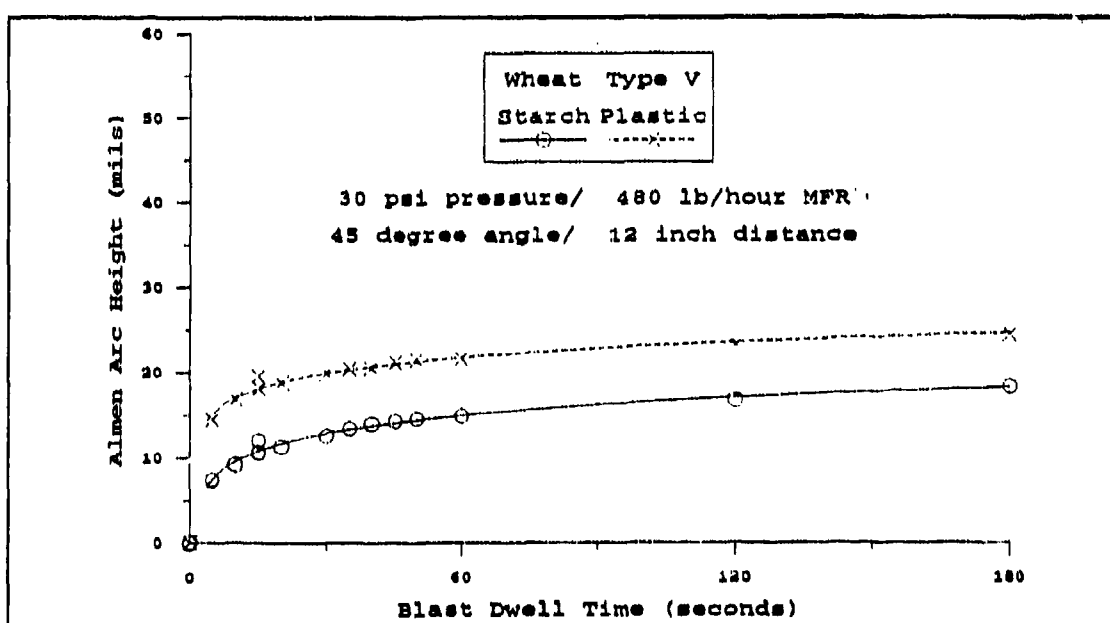


Figure 6. Saturation Response of Wheat Starch and Type V Media for 0.042" Magnesium.

removes the starch residue. Beech concluded that using Scotchbrite was economical for field maintenance of a magnesium control surface, even when Dow #19 treatment is required. However, it is not economical for unfurmed raw magnesium material.

Crack Detection after Dry Blasting

DREP studied the effects of different dry blast

medias on the detection of fatigue cracks on 7075-T6 aluminum, both bare and clad alloys. The effects of wheat starch media were compared to Type V and Type II on 7075-T6 bare aluminum only.

The cracks were prepared on a 12 x 24-inch panel 0.25 inches thick. The cracks were placed in the plate by fatigue using an MTS machine. Stress points were applied at 30,000 to 250,000

cycles at 21 equally spaced locations on each plate. A variety of crack lengths were produced over the entire surface, ranging from 0.07 to 1.1 inch. The plates were blasted at a 30 psi pressure using angles of 45° and 90°, media flow of 660 lb/hour, and a standoff distance of 10-12 inches. Comparative data for all three media types was only developed at the 90° angle. The plates were blasted over the entire surface for two minutes, giving the equivalent of a 1 ft²/minute cleaning rate.

The following method was used in crack detection. Cleaner 9PR551 was applied prior to treatment with fluorescent penetrant 985-P2E and Zyglo developer ZP-9 Formula B. After each blast cycle and LPI treatment, the plates were immediately cleaned with water and alcohol to remove penetrant and developer, then vapour degreased with trichloroethane. Cracks were measured with a calliper under UV light to a precision of ± 0.01 inch.

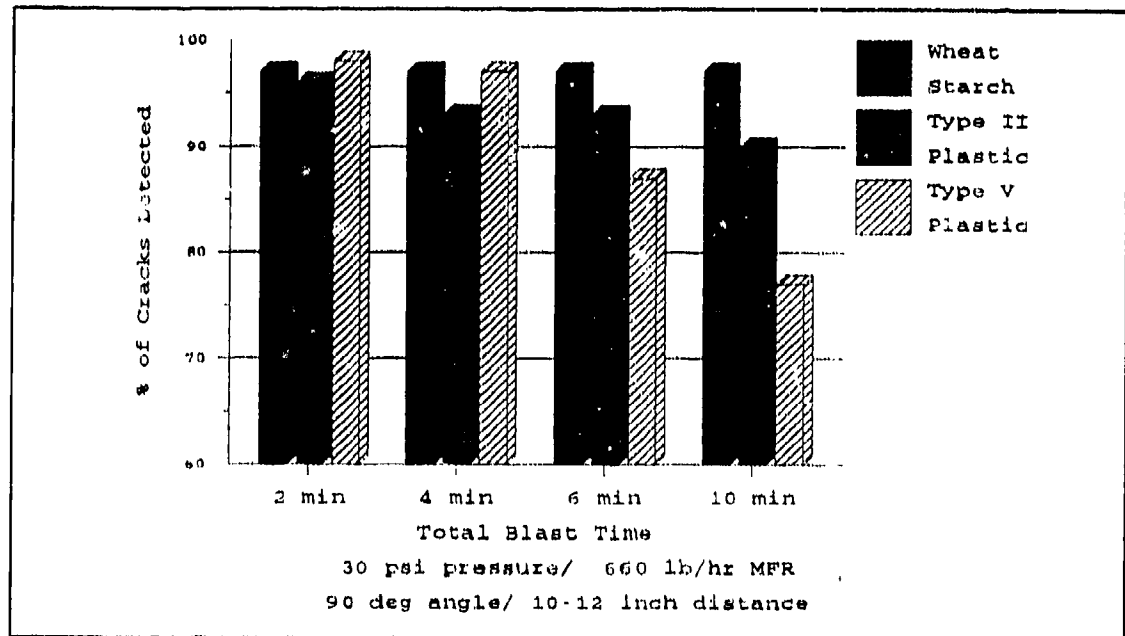


Figure 7. Comparison of Percentage of Cracks Detected on 7075-T6 Bare Aluminum.

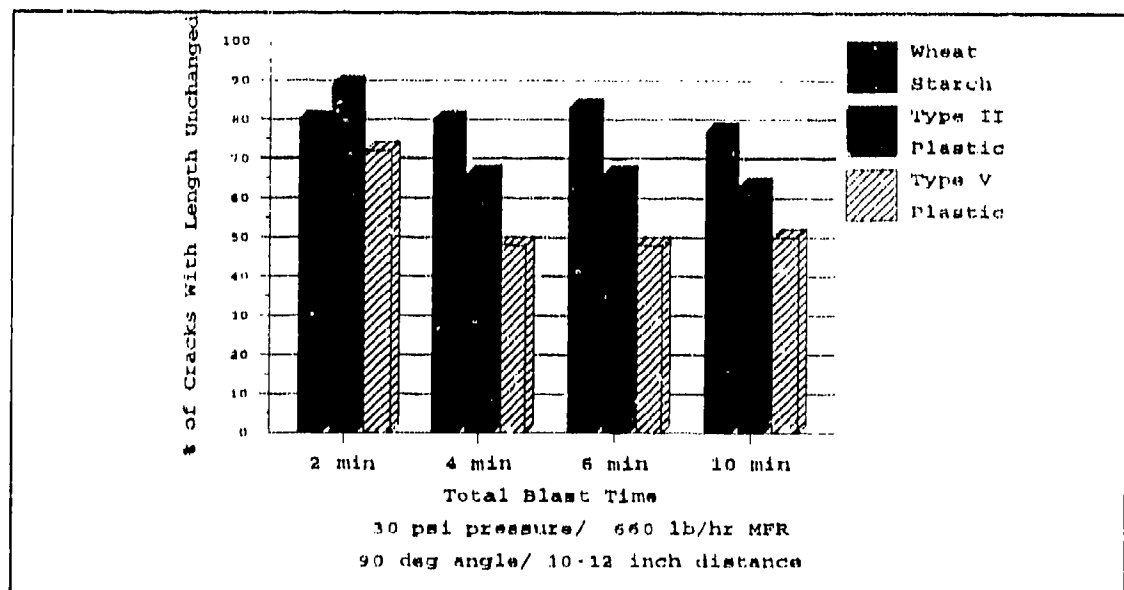


Figure 8. Comparison of Percentage of Unchanged Cracks on 7075-T6 Bare Aluminum.

Figure 7 compares the percentage of cracks detected on 7075-T6 bare aluminum after different blast times with each of the three media types. The results with wheat starch media showed that virtually all cracks remained detectable after each blast cycle. Of the 60 cracks blasted on bare aluminum, only two were not detected after the first blast cycle. These were small cracks measuring 0.10" and 0.198" which branched from a very long crack (1.11"). All remaining cracks were detected through 5 blast cycles. DREP concluded that with wheat starch media, the majority of cracks did not shorten in length and would be detectable in a production environment.

Results with Type V and Type II medias were less favourable in this comparison. Type V media appeared to be more aggressive on the bare aluminum than the Type II media, despite a similar crack distribution on the plates tested in each case. Type V media, when tested at a 45° angle, produced better results on the bare aluminum. Comparative results at the lower angle were not available for wheat starch.

Figure 8 presents the crack detection results on bare aluminum from a different perspective. The percentage of cracks unchanged in appearance (i.e. measured by length) are compared. In the case of wheat starch media, not only were most cracks detectable, but the majority (80%) did not change in appearance during the first three blast cycles.

Crack detection on 7075-T6 bare aluminum proved to be better on surfaces blasted with wheat starch media versus the plastic medias type V and II.

Surface Roughness on Clad Aluminum

Beech Aircraft Laboratory tested the surface roughness produced with wheat starch media on 2024-T3 clad aluminum. Clad panels 0.020" (0.51 mm) to 0.080" (2.03 mm) thick were stripped of a MIL-P-23377 primer without removing the Alodine 1200S chemical film. None of these clad panels were deformed. Table 2 shows the surface roughness measurements

recorded at different clad aluminum thicknesses. Aluminum cladding represents 5% of the front and back (10% of total skin thickness) of an alclad skin up to 0.063" thick. Beyond the 0.063" thickness, clad aluminum is only 2.5% (5% of total skin thickness). Reviewing the data in Table 2, we see that roughness increases with additional surface clad up to 0.040". On the 0.080" clad panel, surface roughness is limited by the fact that less clad is used on the thicker aluminum skin.

Wheat starch media achieves a very smooth surface finish on clad aluminum as shown by these low surface roughness results.

Metal Fatigue Data

Although fatigue data generated by a qualified process lab is not available at this time, Boeing Commercial Airplane Co. will have completed its study on wheat starch media by late 1992. Initial indications look favourable.

Composite Evaluations

Several commercial and military composite stripping programs are underway. On the commercial side, a United Airlines/Boeing Commercial Airplane study will be completed in the fall of 1992.

In this study, the full range of Boeing coatings and composite substrates are being evaluated. The study's objective is to establish both selective stripping and complete coating removal on aged and unaged composite test panels, for both a single and multiple strip sequence.

The coating system used for this test program on the graphite panels is BMS 10-103 Desoto nonchromated epoxy primer and BMS 10-60 type II polyurethane top coat. The fiberglass and Kevlar panels have an initial layer of Desoto conductive coating BMS 10-21 type III, followed by the BMS 10-103 and BMS 10-60 type II system. Composite substrates included in the study are the graphite, fiberglass and Kevlar honeycomb core materials, the fiberglass fluted core (radome), and the graphite laminate and

Table 2. Surface Roughness Measurements on 2024-T3 Clad Aluminum for Wheat Starch Media.

Aluminum Skin Thickness	Clad Layer Thickness	Surface Roughness After Blasting (μ-inches)
0.020" (0.51 mm)	0.0010" (5.0%)	41 (1.02 μm)
0.025" (0.63 mm)	0.0013" (5.0%)	70 (1.78 μm)
0.032" (0.81 mm)	0.0016" (5.0%)	90 (2.29 μm)
0.040" (1.01 mm)	0.0020" (5.0%)	142 (3.61 μm)
0.080" (2.03 mm)	0.0020" (2.5%)	132 (3.35 μm)

graphite honeycomb with EMF (conductive wire mesh).

Preliminary results of the single selective strip cycle showed no indication of internal delamination or fiber damage.

An evaluation was also conducted by the U.S. Army at the Corpus Christi Army Depot (CCAD). Their process laboratory concluded that wheat starch media could effectively remove MIL-SPEC coatings from composite structures, primarily for military helicopters. Resin rich and resin starved S-Glass honeycomb panels, and S-Glass skins from a UH-60A Blackhawk were stripped of MIL-P-23377 epoxy primer and MIL-C-46168 top coat. The S-Glass composites were stripped both selectively (leaving the primer intact), and completely without erosion of the resin layer or fiber damage. This study noted that operator skill is a factor on resin-starved substrates. Excessive dwell times in one spot beyond 3-4 seconds would lead to damage of the resin layer first, and then fiber damage. Optimum parameters for stripping these composites, using a 3/8-inch nozzle, were a pressure of 25 psi, a standoff distance of 6-8 inches, angles between 30°-70°, and a media flow of 480 lb/hour.

A resin-starved Kevlar formed skin panel from an AH-64 Apache was also included in the CCAD study. For complete coating removal, operator skill was found to be critical on the Kevlar where minimal dwell time was needed to avoid damage. Kevlar materials are best stripped selectively, leaving the primer intact if possible.

DREP (Canadian Forces) investigated effects on graphite-epoxy substrates similar to those found on CF-18 fighter aircraft. Coatings removed were the MIL-P-23377 primer and the MIL-C-83286. Scanning Electron Microscopic examination showed no cracking of the epoxy resin layer or fiber damage. The graphite panels were blasted for extended dwell times beyond 60 seconds at 40 psi pressure and a standoff distance of 12 inches.

In conclusion, there is considerable variety in the composite structures used on aircraft. The experience gained in these composite evaluations shows that some epoxy resin systems withstand starch blasting better than others. Several programs have proven that high temperature cured or toughened epoxy resins are not removed from composites when stripping with wheat starch media, nor is fiber damage observed. With softer resin systems or resin-starved composites, operator skill becomes much more of a factor in achieving satisfactory results.

3 PRODUCTION EXPERIENCE WITH DRY WHEAT STARCH STRIPPING

Airframe stripping of small corporate and regional aircraft began this summer at Hunting Aircraft Inc. (formerly Field Aircraft Inc.) in the U.S. A Pauli & Griffin three nozzle system, specifically designed for starch media, was installed in Hunting's new completion center. A dedicated hanger bay, measuring 100 feet by 100 feet, is used to dry strip entire airframes. A Beech King Air 200 was one of the first aircraft stripped in this facility. On this particular aircraft, skin thicknesses varied down to 0.016" on flight controls and 0.020" on the airframe. All surfaces, except composites, were stripped to a pristine finish. No metal warpage was observed even on the thinnest skins. Seventeen man-hours on each of three nozzles were needed to dry strip the airframe and flight controls. An estimated strip rate of 0.6 ft²/minute was achieved. Military and commercial polyurethane paints are generally easier to remove than paint systems found on smaller corporate aircraft.

The system at Hunting features several important items required for any wheat starch system. The compressed air supplied to the three nozzles (680 cfm) is dried with a refrigerant air dryer to a 35-40°F dew point. Dry compressed air is usually recommended for any dry blast system, a recommendation not always respected. With wheat starch media, a compressed air dryer is mandatory.

Since Atlanta can encounter very hot, humid summers, a moisture control system is used as a precautionary measure. Dry air is fed into product hoppers to control product storage conditions, particularly during extended shutdowns. Moisture effects on the media have not been encountered at this facility.

The Hunting system includes a dense particle separator designed to remove contaminants, such as sand and metal, from the wheat starch media. Because the finish on aluminum is very smooth with wheat starch media, low levels of heavy particle contamination are noticeable. The finish with plastic media blasting will generally mask the presence of a much higher level of contaminants. An effective dense particle separator is highly recommended for any wheat starch dry strip hanger.

Experience on the first few aircraft at Hunting has also shown which masking materials and methods work best. Three masking tapes have been identified as being effective with wheat starch media. A 3M YR-5005 (quite different from the YR-500 used with plastic media) and a

Bron Tape BT-818 (Bron Tape Inc.) have performed the best. A black vinyl tape Permaceel P-320 (Permaceel Inc.) is also effective, but cannot withstand the starch blasting for the same length of time.

New Developments on Disposal

Considerable work has been done in past years on biodegradable products. In the effort to develop degradable products, composting technology has received much attention.

Degradation of starch dust and paint, via similar composting technology, is currently being investigated at Archer Daniels Midland. Since starch media has a 100% carbohydrate content, proper aerobic digestion in a compost system can reduce waste volume substantially, leaving primarily paint residues behind.

Composting experience with degradable products show that proper aeration is essential in order to keep the digestion process aerobic. Aerobic, as opposed to anaerobic, would favor bacteria which require oxygen. The effects of heavy metals on compost activity needs to be investigated further. Once the ideal compost system, bacterial organism, and its required supplements are identified, efficient composting could degrade starch dust within days.

4 CONCLUSION

The wheat starch dry stripping process has evolved into a viable alternative to chemical paint strippers. Both material process laboratory work and actual production experience is proving that wheat starch media provides the best possible finish from a dry stripping process. Combined with the potential dry toxic waste reduction possible with biodegradation of starch, wheat starch blasting offers an environmentally and ecologically sound option. Recent work in the area of composting stands to substantially minimize the dry toxic waste generated.

From a production perspective, wheat starch blasting is one of the few processes that can achieve excellent results in a manual system. Yet, this process also has the potential to benefit from robotic application.

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IATA TaskForce 'Paintstripping'

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SUMMARY

In 1990 the IATA established a task force to stimulate the development of alternatives for chemical stripping of commercial aircraft. The IATA TaskForce 'Paintstripping' objectives are:

- to identify the most promising, current alternatives for short term implementation;
- to prepare a document containing requirements for the development of alternatives;
- to stimulate the information exchange.

After the September 1992 meeting the TaskForce will report back to IATA.

The most tangible result of the TaskForce is the IATA Guidelines containing requirements for the qualification of stripping processes.

1. INTRODUCTION

The airframe maintenance business is encountering increasing problems with the current chemical stripping processes. For, those processes are using methylene chloride and phenol containing strippers, which are hazardous to the workers and emit chlorinated hydrocarbons, known to be detrimental to the ozone layer.

For several years alternatives to chemical stripping are investigated for aerospace purposes. In the mid 80's plastic media blasting became available, which in its turn stimulated the development of other mechanical blasting processes (e.g. carbon dioxide-pellet blasting, waterjetting).

However, the progress made was slow and the development efforts did not result in a practical and economical feasible process for stripping commercial aircraft.

2. HISTORY OF THE TASKFORCE

Early 1990 members of the European Advisory Committee on Materials Technology (EACMT), a

committee of the Association of European Airlines (AEA), discussed the problem of stripping aircraft structures and investigated the reasons behind the slow progress made on alternatives.

It was concluded that the main problem lays in the fact that most developers of the new processes are not familiar with the aerospace industry and its typical requirements. This result in laborious testing, and long presentations on test results, without using the proper basic test methods prescribed by the aircraft manufacturers (better: Original Equipment Manufacturers, OEM's). Test methods often differ amongst the OEM's, but performing the correct tests is essential as they form the basis of the OEM approval of maintenance processes. And without OEM approval no commercial airline is able to introduce a maintenance process of this kind.

Furthermore, the OEM's interest in stripping processes was low. Late 1980's mainly plastic media blasting (PMB) was researched*, sometimes approved, for special applications. It is this focus on PMB that worried the airlines, as they do not regard PMB as a viable method of stripping commercial aircraft structures.

*). To illustrate this: the 1988 DoD/Industry Advanced Coatings Removal Conference contained 25 technical papers on PMB, and only 3 on other processes (laser stripping).

In October 1990 the EMAC-48 (the 48th meeting of the Engineering and Maintenance Advisory Committee) of the International Air Transport Association (IATA) decided to establish a task force to deal with the problem of stripping commercial aircraft. The EACMT-committee was therefore enlarged with representatives of other IATA-members and, also the major OEM's were requested to participate in the IATA TaskForce 'Paintstripping'.

3. TASKFORCE COMPOSITION

The TaskForce 'Paintstripping' comprise representatives of the following OEM's and airlines:

Boeing Commercial Airplanes, Airbus Industrie (incl. Deutsche Airbus, Aerospatiale and British Aerospace), McDonnellDouglas, Fokker Aircraft and United Technologies - USBI; AirFrance, Alitalia, British Airways, Iberia, Deutsche Lufthansa, Northwest Airlines, Swissair, Sabena, United Airlines, UTA, and is chaired by KLM Royal Dutch Airlines.

On the TaskForce meetings the aviation authorities are also invited. Furthermore the meetings are frequently attended by other IATA-members as observers.

4. OBJECTIVES

The TaskForce's objectives are:

1. To identify the most promising alternative stripping processes for the maintenance of commercial aircraft;
2. To prepare a document, containing the technical requirements for the qualification of processes for stripping aircraft structures;
3. To stimulate the information exchange between the parties involved, i.e. researchers, suppliers, OEM's and airlines.

The objectives must lead to a harmonization and concentration of development efforts, to minimize testing by supplying accepted testmethods and requirements, and to accelerate the approval process by aircraft manufacturers and airworthiness authorities.

4.1 Most promising alternatives

It was decided to compile information on all stripping methods available and to judge the overall performance against the commercial airlines' requirements. For this purpose two questionnaires were sent out to the suppliers of stripping methods and all TaskForce members respectively. (Many taskForce members themselves are involved in the development of alternatives together with the industry.)

Through the questionnaires information was obtained regarding the following items:

1. Airline requirements (see Appendix A):

- Stripping objects: aircraft type, frequency, substrates;
- Economy: down time, investments, costs/m², masking;
- Coatings to be stripped;
- Waste management;
- Environmental and safety aspects, now and in the future;
- Operational environment.

2. Alternative stripping methods:

- Status of the development;
- Damage to substrates/restrictions;
- Waste production and composition;
- Economics: masking, strip rate, costs, investment.

Although comparison of the alternatives is complicated, and airline requirements vary, it is concluded that, based upon the collected information, the most promising alternatives for short term implementation in commercial maintenance are (status 1991):

- Automated high pressure water blasting;
- Aquastrip process, incl. paint softening with environmentally acceptable chemicals;
- Wheat starch blasting (manually for aircraft components; automated for aircraft);
- Ice pellet blasting, incl. paint softening with environmentally acceptable chemicals;
- Chemical stripping using environmentally acceptable and safe products, if necessary in combination to a dedicated paint system.

For most airlines chemical stripping still remains the most attractive method, because the lack of a dedicated facility for stripping large aircraft. Stripping normally is performed in a paint or maintenance hangar (during mechanical maintenance). The use of less aggressive chemicals probably requires less chemical resistant coatings or the application of an intermediate strippable paint layer. This implies that the implementation of this process is not possible on short term.

Also it was concluded that selective stripping, i.e. stripping of the topcoat only, is an option to enhance stripping rates, decrease the risk of damage and the magnitude of the repaint job.

4.2 The Paint Stripping Document

The development and research for alternative stripping methods is progressing slowly. This is partly due to the lack of standardization in the research programs. The suppliers will investigate according to specific methods prescribed by the various OEM's or to MIL-specifications. This means that the complete testprogram often does not meet the requirements of the individual OEM's, thus approval for certain aircraft types will hold and other tests are necessary.

The TaskForce concludes that it is necessary to enhance the developments by issuing a document containing the requirements for the qualification of processes for stripping aircraft structures of different commercial aircraft types. To fulfil this function:

- it is required that all OEM's concur with its content and that their individual documents shall be written to reflect this document;
- it is understood that OEM documents and manuals may have some deviations from the document to address certain aspects of their own aircraft, its design features, materials and coatings;
- the document needs to be approved by the airworthiness authorities;
- updating of the document needs to be secured. Therefore an international standards organization should hold the custodianship.

The, so called, Paint Stripping Document deals with both metallic and composite materials. It covers mechanical (wet and dry) as well as chemical stripping. Included are requirements, recommended testmethods, test panel preparation and test results on e.g. media residues, damage to substrates (fatigue, residual stress, corrosion), substrate temperatures, roughness of surface after stripping, and (chemical) degradation of composites. A minimum of five stripping cycles is prescribed.

Note that the Paint Strip Document does not judge the economic performance of the process, nor describes any environmental or safety aspects, as these items are airline/country related.

At the moment a preliminary version of the Paint Strip Document is completed. For some requirements, multiple test methods are included, where the TaskForce could not come to agreement. This version will be discussed during the next

TaskForce meeting (September 10 and 11, 1992), and when accepted released as an IATA Guideline. Furthermore the TaskForce will choose a route to come to a specification and the custodian. Proposed organizations are SAE and ISO.

For the time the Paint Strip Document is not under the custodianship of an international standardization organization, the route to approve a process is envisaged as follows:

1. the airline/supplier contact the OEM('s) to decide from the Document which tests are applicable and need to be performed;
2. the test results are discussed with the OEM, which will state to have "No Technical Objection" to apply the stripping process to the OEM-type aircraft;
3. the airline contact the relevant airworthiness authorities to obtain approval;
4. the airline implement the process in the maintenance operation.

In the future, the OEM can directly refer to the international specification in their maintenance manuals.

4.3 Information exchange

During the TaskForce meetings the latest developments are discussed on the selected alternatives. Where possible, comparable research programs between members are linked to obtain a synergistic effect and consequently speeding up of the developments. Also, duplication of testing is hereby excluded.

Furthermore a presentation on new developments can be brought into the meeting on request of one of the members.

The large interest of the commercial airlines in chemical stripping has resulted in organizing a meeting with the coatings and stripper supplying industry (September 9, 1992). This meetings' objective is to stimulate the development of alternative strippers, in combination to the present aerospace coatings e.g. future dedicated coating systems.

The TaskForce presents the airlines' requirements (i.e. the technical and economical process envelope) for a chemical stripping process. From the industry it is expected to present their vision for the future and research involved. This way any contradictions in the objectives pursued by the parties involved will come to the surface and can be rectified.

Furthermore the TaskForce tries to stimulate joined research between the coatings and chemical industry.

5. Future of the TaskForce

On the September meeting the TaskForce decides on its future.

When agreement is obtained on the most important item, the Paint Stripping Document, the TaskForce probably is transformed into a working group for the preparation of the specification. This working group however will operate under the rules of the applicable standardization organisation, and not IATA.

Therefore, IATA (EMAC) will be proposed to liquidate the TaskForce 'Paintstripping'.

The achievements of the TaskForce are by that time:

- publication of the IATA Guidelines for the technical qualification of paint stripping processes;
- joined research and information exchange by the leading airlines in this field for the development of alternative processes;
- supplying information to the coatings and chemical stripper industry for the future airline's needs and requirements in stripping commercial aircraft.

*August 1992
Thomas Mooy*

APPENDIX A: 'AVERAGE' AIRLINES' REQUIREMENTS

1. Objects of stripping process:

Boeing, Douglas and Airbus manufactured.
All types, all series upto 100% decorated.

Size: 600 to 2000 m² to strip.

Substrates to be stripped:

Aluminium alloys: 2024T3, 7075T6, bare, cladde,
anodized and/or alodined.

Magnesium. Titanium. HSS. Cadmium plated metals.

Composites: Glass-, carbon- and kevlar-fibres/epoxy (250
and 350 F cured). 250 F cured hybrids.

Thorstrand and Flamesprayed composites.

2. Economy of stripping:

Downtime of aircraft:

2 to 3 days.

Investments (present):

Very low.

Total costs:

35 to 50 US\$/m²

Effectivity:

2 to 3 m²/hour per man, incl. all pre- and after treatments.

3. Coatings to strip:

From metals:

1. Chromates-containing epoxy and polyurethane primers.
Polyurethane topcoats.

2. Washprimer. Chromates-containing and chromate-free
primer. Polyurethane topcoats. (Polyurethane clearcoat).

Epoxy conductive coating. Epoxy and polyurethane
primers. Polyurethane topcoats.

5 (metals) to 8 (composites).

Preferred.

From composites:

Strip cycles per aircraft lifetime:

Selective stripping?

4. Waste management:

Waste treatment facility:

None.

Disposal:

By licensed companies.

5. Environmental & Safety issues:

Operator requirements to:

Chemicals:

Methylene chloride: 100 ppm (to be reduced).

VOC emission: 0 to 20 mg/m³ (to be reduced) or 420 g/l
max. content in products.

Low Threshold Limit Values for acids and alkalis.

Noise:

80 dB(A) max.

Dust:

Total 10 mg/m³ max.

Cd 0.02 mg/m³. Cr 0.025 mg/m³ (to be reduced).

6. Operational environment:

Facility:

Normal maintenance hangar or paint hangar (telescopic
platforms available).

50 % in which large quantities of water can be handled.

SELECTIVELY STRIPPABLE PAINT SCHEMES

by

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SUMMARY

In order to meet the requirements of more environmentally acceptable paint stripping processes many different removal methods are under evaluation. These new processes can be divided into mechanical and chemical methods.

ICI has developed a paint scheme with intermediate coat and fluid resistant polyurethane topcoat which can be stripped chemically in a short period of time with methylene chloride free and phenol free paint strippers.

Hence the common use of methylene chloride strippers activated with aggressive ingredients like phenol.

With the need for methods which are both safer and more environmentally acceptable consideration of methods other than chemical means is required.

Several mechanical methods evaluated today as environmentally acceptable have the capability of removing today's high performance paint systems but have many limitations due to side effects or high investment cost.

This paper, however, only deals with chemical stripping involving a development which makes the process much easier whilst retaining good performance for the essential paint properties. This ability then leads the way to environmentally acceptable chemical stripping. The first step in this development which proves the principle is the use of an intermediate coat which allows a Skydrol resistant polyurethane topcoat to be stripped in remarkably quick time with a non phenolic stripper but with methylene chloride.

By the correct choice of intermediate coat it is possible to introduce solubility to certain solvents which could be used in a stripper whilst still retaining resistance to aircraft fluids.

1. PREFACE

Conventional aircraft paint is designed to have as good adhesion as possible and to have high resistance to fluid attack and to mechanical damage. These features make a paint which has very good performance but one which is very difficult to remove. Today paint systems are usually removed by chemical stripping. But in order to counter the fluid resistance and the adhesion a very powerful stripper is needed.

Thus easy strippability can be introduced whilst the adhesion and fluid resistance properties can be maintained.

To do this it is necessary to have a very careful choice of resin in the intermediate coat.

ICI achieved this and has pioneered this principle starting with application to Airbus A 300 in 1974.

2. HISTORICAL BACKGROUND

The first generation of a selectively strippable scheme had been developed in cooperation between MBB and Winderhold in 1974.

The so called Zwischenschicht or Couche X was used on Airbus A 300 number 10 up to approximately number 100. Some problems of intercoat adhesion between Polyurethane primer and Couche X led to the replacement of this paint scheme. In 1980 Airbus moved to a wash primer scheme based on test results with a similar ICI system on a BAe 125 aircraft.

Because of the variable strippability with the wash primer scheme ICI continued to develop the original intermediate coat scheme and offered an improved scheme for consideration by Fokker for the F100 consisting of an epoxy primer, intermediate coat and polyurethane topcoat.

This system proved to be the best in the test program and superior to the wash primer system. Consequently it was chosen by Fokker in 1986 for the exterior paint system for the F100.

At a similar time this same type of scheme was seen to be a possibility for military aircraft where the combination of easy strippability and high chemical resistance was required. Painted panels on Harrier aircraft in flight service and evaluated by the UK MOD proved the stripping performance.

In 1987 Airbus A320 number 2 aircraft was also painted with the ICI intermediate coat scheme, using a flexible topcoat.

Application and subsequent performance

were satisfactory. In July 1990 the aircraft was stripped using a non phenol stripper. Lifting of the topcoat occurred in 5 minutes and complete removal was possible within 30 minutes leaving the epoxy primer in perfect condition.

This has confirmed that an intermediate coat scheme which is fluid resistant with a flexible topcoat works in practice and that ageing on an aircraft does not reduce its effectiveness.

3. SELECTIVE STRIPPABILITY

Selective strippability can be achieved by either using an intermediate coat or a barrier coat. The main difference between these two systems is the removability of the intermediate coat whereas the barrier coat is intended to stay on the primer during the stripping action.

The repainting process is similar in both cases. Since a barrier coat is not removed in the stripping process the final repainted scheme has an additional layer of paint.

As a consequence the coating thickness builds up in multiple stripping/repainting actions.

Work on barrier coat has shown that it is very difficult to get a good balance between adhesion and strippability in practice. Also for inspection of a stripped aircraft the barrier coat does not allow the detection of cracks in the primer.

The two principles are shown in figure 1 and 2.

After considering the advantages and disadvantages we have chosen at the present to develop the intermediate coat principle mainly for reasons of it working well in practice.

Figure 1

INTERMEDIATE COAT SCHEME OPERATION

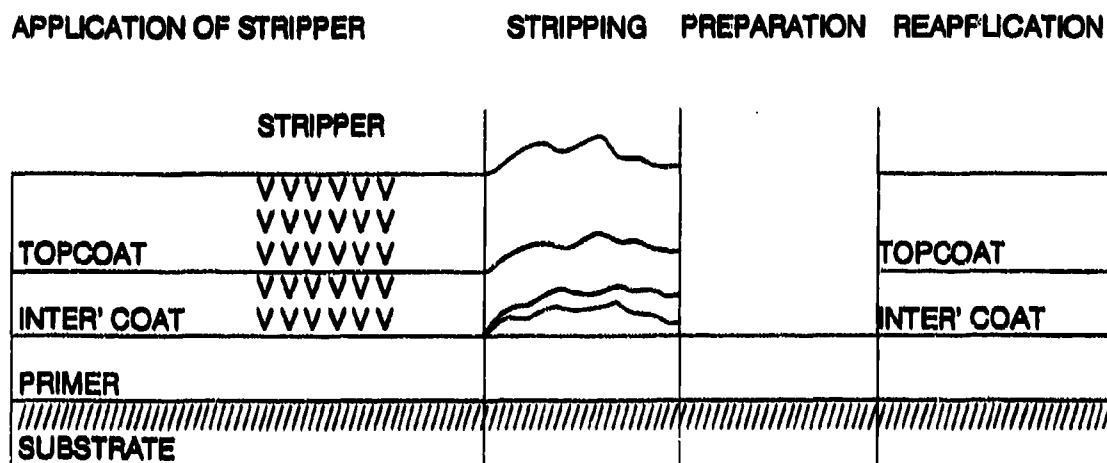
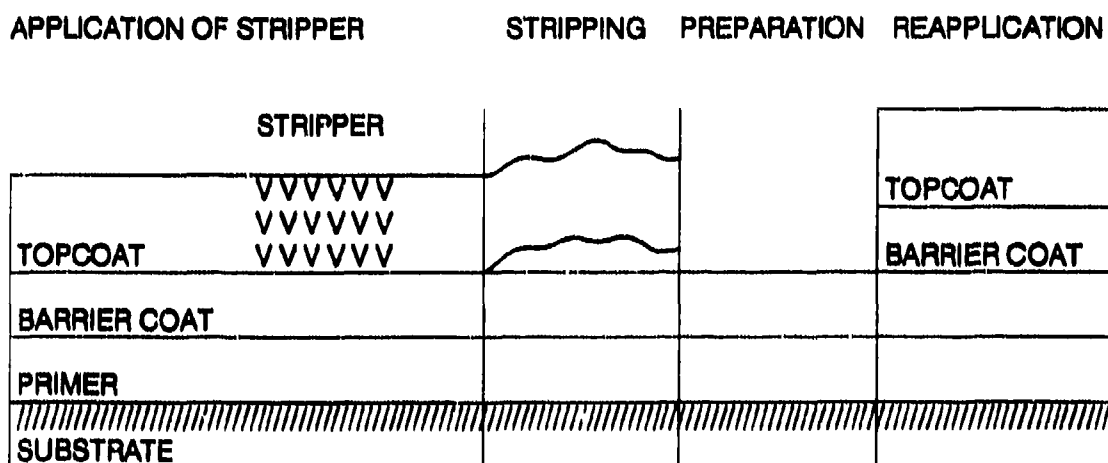


Figure 2

BARRIER COAT SCHEME OPERATION



4. CHALLENGE OF WEAKER STRIPPERS

So far the evidence has confirmed the feasibility of the intermediate coat scheme to offer easier strippability with methylene chloride strippers. A further dimension was introduced when the need arose to achieve this with non chlorinated solvent strippers.

Working closely with major stripper manufacturers ICI has developed the Intermediate Coat II system.

It consists of an epoxy primer as before the ICI Intermediate Coat in a modified form and a very careful choice of polyurethane topcoat.

Tests done on aged panels in a number of independent laboratories confirm that it is possible to strip this type of scheme in less than 2 hours with non halogenated strippers also in neutral form.

At the same time this scheme achieves other paint properties, including Skydrol resistance. It has been tested and found to meet the requirements of Airbus specification NT 10028.

The Intermediate Coat II system has been applied on a British Airways Concorde, on a Domier 228 and at Lufthansa.

These will be used to test the strippability after ageing in flight service with environmentally acceptable strippers to confirm the good results which have already been obtained on panels in the laboratory.

Three topcoats have been evaluated to work with this scheme in this way. They include options which offer UV-resistance, UVR with flexibility, and UVR with low VOC.

5. COMPOSITE

Traditionally, painted composite areas have had to be treated differently when painted metal areas have been chemically stripped. This is because many composite materials are susceptible to attack from methylene chloride.

The idea has been put forward that if a barrier coat is incorporated into the paint system the composite can be protected from detrimental attack from the stripper. But in a practical situation this principle is invalid because one can not prevent the occurrence of cracks in the barrier coat where penetration to the composite is possible.

The alternative solution to this problem is to design the paint system such that it can be stripped with a chemical stripper which itself will not be detrimental to the composite.

This is achievable using the ICI Intermediate Coat II principle.

The Intermediate Coat II paint system on composites has been successfully stripped using non chlorinated strippers. These strippers have been tested and they were found to have no damaging effect on the composite in relation to the IATA stripper specification.

6. CONCLUSION

Flight experience dating back to 1974 on ICI Intermediate Coat scheme support the feasibility of such a scheme offering the combination of good paint properties and easy strippability.

More recent work has shown that this concept can be extended to allow for strippability in a short time with environmentally acceptable non chlorinated solvent strippers. This can be done with a range of advanced topcoats offering different properties.

This also leads to the possibility of chemical stripping from composite without damage. From an economic point of view the main advantage of an intermediate coat system is to have an environmentally acceptable stripping process which can be operated in existing facilities without the need for new investment.

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